ERDC/CRREL TR-11-10

Cold Regions Research and Engineering Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

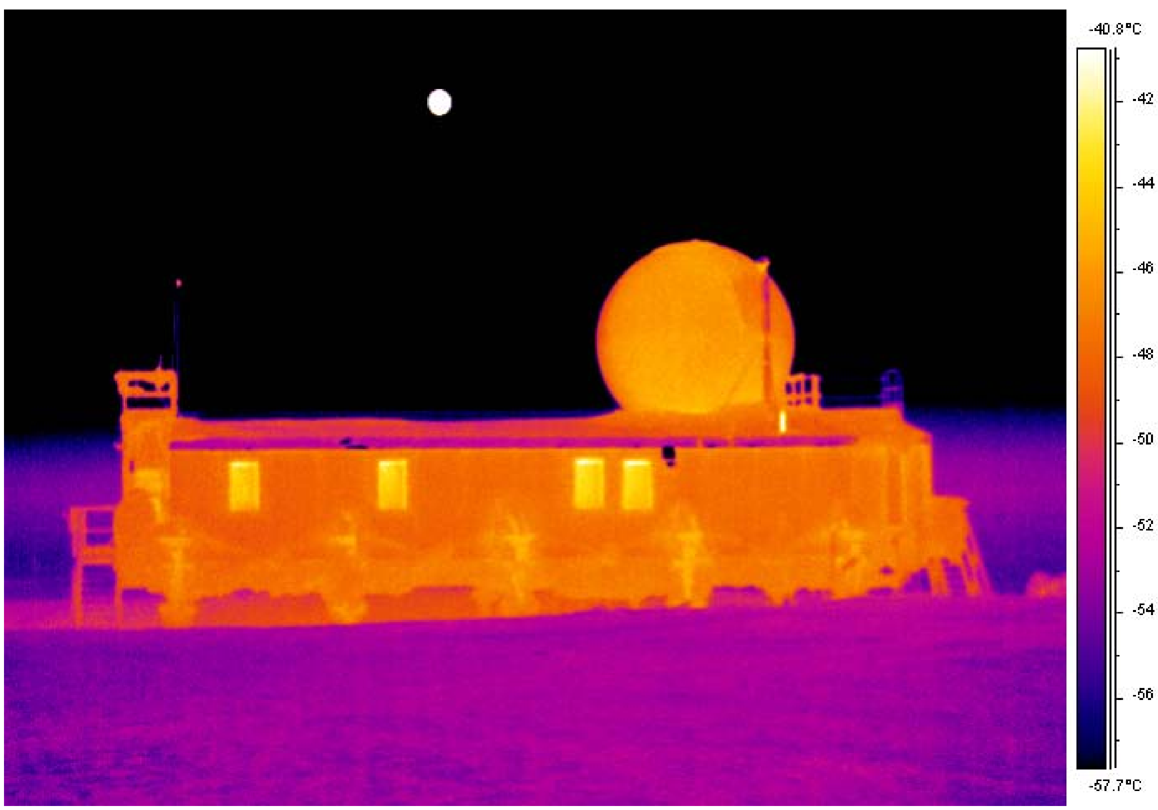
Engineering for Polar Operations, Logistics, And Research

Engineering Assessment of Big House at Summit Station, Greenland

Final Report

Lynette A. Barna, Keran J. Claffey, James S. Buska, and Jennifer L. Mercer

April 2011



Engineering for Polar Operations, Logistics, And Research

ERDC/CRREL TR-11-10
April 2011

Engineering Assessment of Big House at Summit Station, Greenland

Lynette A. Barna, Keran J. Claffey, James S. Buska, and Jennifer L. Mercer

Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover,NH 03755-1290

Final report

Prepared for National Science Foundation, Office of Polar Programs
Research Support and Logistics Division
Arlington, Virginia

Abstract: An infrared (IR) assessment was conducted of the main administration building located at Summit Station, Greenland. The building, known as the "Big House," was constructed in 1989 on a permanent snowfield at the apex of the Greenland Ice Sheet. Summit Station typically receives 65 cm of annual snowfall. Accumulating snow combined with blowing and drifting can completely bury a structure in several years. For this reason, the Big House is elevated above the snow surface on steel support columns and it is periodically lifted to maintain clearance above the snow surface. The Big House has been lifted four times for a combined total height of 15 m. The lifting process can damage buildings by causing racking. This IR survey was conducted to identify existing deficiencies in the building that may diminish the energy efficiency or compromise the structural performance, reducing the building's service life. This evaluation found that, in the extreme climate where the Big House is located, the structure is performing quite well after 20 years of service. The most significant issue is heat loss in localized areas through the building envelope. No major structural issues were observed.

Contents

Figures

Tables

Preface

This report was prepared by Lynette A. Barna, James S. Buska, and Jennifer L. Mercer of the Force Projection and Sustainment Branch (FPSB), and Keran J. Claffey of the Terrestrial and Cryospheric Sciences Branch, U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

The authors wish to acknowledge the members of CH2M Hill Polar Field Services team who generously provided support throughout the project and made for a successful field visit: Sandy Starkweather, Jay Burnside, Mark “Commander” Melcon, Ken Keenan, Geoff Miller, Ken Jesson, Geoff Phillips, Tracy Sheeley, and Rosemarie Garofalo.

Funding for this work was provided by the National Science Foundation, Office of Polar Programs, Research Support and Logistics Division, Arlington, VA.

This report was prepared under the general supervision of Dr. Justin Berman, Chief, Research and Engineering Division; Dr. Lance Hansen, Deputy Director; and Dr. Robert E. Davis, Director, ERDC-CRREL. The ERDC Commander is COL Kevin Wilson. The ERDC Director is Dr. Jeffrey P. Holland.

Unit Conversion Factors

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
mm	millimeters	3.93701×10^{-2}	inches	in.
cm	centimeters	3.93701×10^{-1}	inches	in.
m	meters	3.28084	feet	ft
m	meters	1.09361	yards	yd
km	kilometers	6.21371×10^{-1}	miles (statute)	mi
		Area		
mm^2	square millimeters	1.55000×10^{-3}	square inches	$In.^2$
m^2	square meters	1.07639×10^{1}	square feet	ft^2
m^2	square meters	1.19599	square yards	yd^2
		Volume		
mL	milliliters	3.38140×10^{-2}	fluid ounces	fl oz
L	liters	2.64172×10^{-1}	gallons	gal
m^3	cubic meters	3.53147×10^{1}	cubic feet	ft^3
m^3	cubic meters	1.30795	cubic yards	yd^3
		Mass		
kg	kilograms	2.20462	pound-mass, avoirdupois (avdp)	lbm
g	grams	3.52740×10^{-2}	ounces (avdp)	oz
		Density		
kg/m^3	kilograms per cubic meter	1.68555	pound-mass (avdp) per cubic yard	lbm/yd^3
kg/m^3	kilograms per cubic meter	6.24280×10^{-2}	pound-mass (avdp) per cubic foot	lbm/ft^3
		Temperature (exact)		
°C	degrees Centigrade	1.8 × (°C) + 32	degrees Fahrenheit	°F
°C days	degrees Centigrade days		degrees Fahrenheit days	°F days
		Pressure or Stress		
MPa	megapascals	1.45038×10^{2}	pound-force per square inch	psi

Summary

The Big House at Summit Station, Greenland, is the main facility supporting overall station operations, providing common areas for dining, washing, and leisure for camp attendees and staff. The Big House has served in this capacity since its construction in 1989. As the National Science Foundation (NSF), and its operations contractor CH2M Hill Polar Field Services (CPS), considers the long-range plan for Summit Station, the current condition of the Big House was assessed for two reasons: 1) to improve the energy efficiency of the building by identifying existing deficiencies that may be addressed, and 2) to identify structural improvements and rehabilitations that may increase the building's service life.

Personnel from the U.S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (ERDC-CRREL) visited Summit Station from 24 to 29 April 2010 to conduct an infrared (IR) survey. Thermography is a useful tool for quickly and easily identifying variations in the thermal properties of buildings that result in temperature changes. Deficiencies attributable to inadequate insulation, drafts, or damage from moisture, which otherwise may not be readily identified with the naked eye, are revealed through IR images. In the case of the Big House, disturbances that have resulted from lifting the building were also considered.

Given how well the Big House has performed over the past 20 years, there are many lessons that have been learned about operating and maintaining an elevated structure of this type in harsh conditions. These "lessons" should be documented to help others better understand what has worked successfully and what has not. Additionally, these lessons from the Big House provide an excellent knowledge base from which to draw for the long range plan for Summit Station.

There are two deliverable items with this project: this technical report and a companion website:

http://www.crrel.usace.army.mil/sid/SummitGreenland/

The website shows the full complement of IR and visual exterior and interior imagery of the Big House, along with plots of temperature showing the changes at specific locations. This report, in its entirety, presents a snapshot of the condition of the Big House as observed during the field visit and offers select visual examples of locations within the building envelope that are performing well along with others that exhibit deficiencies. This summary section of the report was written, if needed, to function separately from the technical report to capture the key components of the study.

Infrared imagery

In all, roughly 1050 exterior and interior IR images were collected during the field visit. A large selection of images is shown at the website address above. To reduce the effect of solar loading, the exterior IR survey was performed between the hours of 2130 to 0400 during twilight when the sun set below the horizon, but some light remained in the sky. Air temperatures at the time of the exterior IR survey averaged about −31°C. Both of the CRREL IR cameras are rated to operate in environments as low as −40°C, and the temperatures encountered at Summit Station did not interfere with the IR survey. The interior temperature of the Big House is maintained at approximately 20°C; therefore, there was no issue acquiring images with a temperature differential between the exterior and interior conditions.

Indoor temperature and relative humidity variations

Indoor temperature and relative humidity (RH) measurements were made at 1-minute intervals during the field visit using four dataloggers. The main common area and the kitchen were monitored during the entire visit. In an effort to collect readings from as many locations as possible, roaming dataloggers were initially set for at least 24 hours in the west vestibule and the mechanical room and then re-positioned in the east vestibule and laundry/bathroom. Coordination with CPS allowed for the data collection to continue through the summer season in the main room and kitchen.

Racking and penetrations

Overall, the Big House is performing very well, given the age of the structure combined with the building being lifted four times for a rough total height of 15 m. Penetrations through the building envelope are the prin-

cipal sources of energy loss in the structure. A sketch showing the layout of the building is shown in Figure S-1 to orient the reader on locations referred to in this section. An inclusive list was generated by CPS personnel, locating and describing existing penetrations. While a number of these were anticipated, including doors and windows, there were also many smaller holes identified because of running cables for sensors and connection points (bolts) that act as supports. Several additional penetrations were identified during the ERDC-CRREL field visit, primarily ones that were not as easily visible. Major penetrations to the various building surfaces (walls, roof, and base), along with recommendations for mitigation, are noted here.

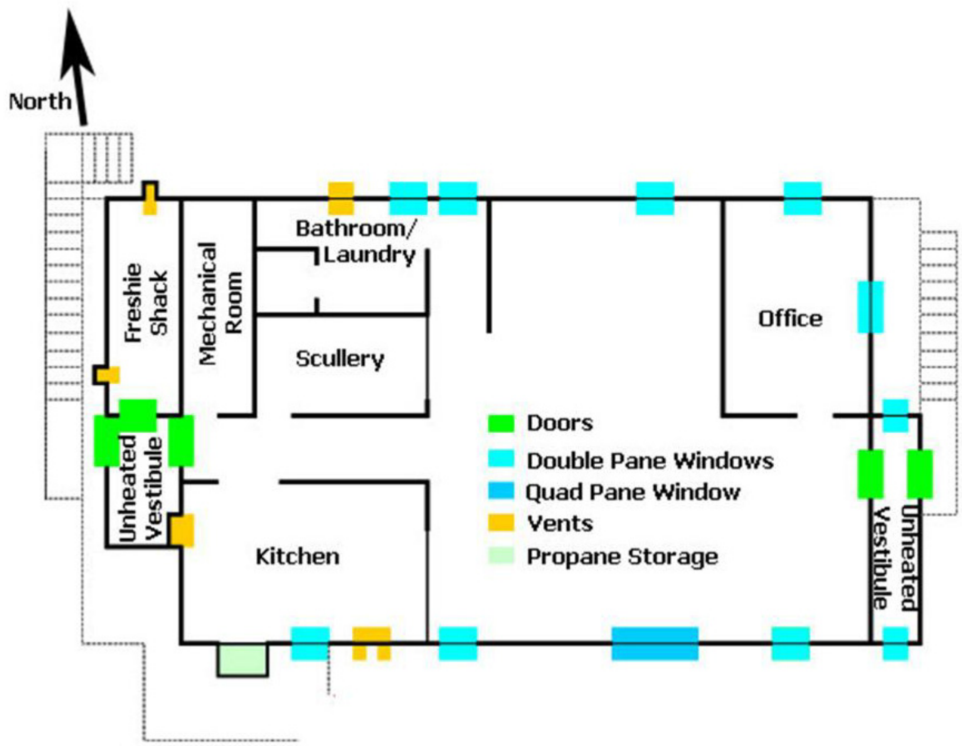


Figure S-1. Plan view of Big House at Summit Station, Greenland.

Racking

Significant impacts from the periodic lifting of the building were not observed in the IR imagery. As an example, separation between seams in abutting structural insulated panels (SIP) in the walls was minor. A typical

seam is shown in Figure S-2. The IR and visual images are of the north interior wall in the dining area.

Figure S-2. Vertical seam between SIPs does not show separation (north interior wall in dining area).

Vents

At the time of the IR survey, an air vent centrally located on the north wall in the laundry room was a direct pathway for cold air to infiltrate into the building. This through-the-wall vent is no longer an issue as it was removed later during the 2010 summer season. The hole was insulated and sealed (CPS 2010). Another possible solution would be to relocate this vent to an internal location, such as the wall between the laundry room and scullery, or the wall between the laundry room and hallway. Moving this warm, moist air within the Big House would serve to disperse the humidity where it is needed into the main room. This would also alleviate the ice buildup on the north exterior wall.

The vent for the clothes dryer in the laundry room was another penetration where the mixing of cold air with the expelled heat from the dryer created ice buildup on the outside of the building.

IR imagery taken from the outside of the Big House shows the impact of stove vents expelling warm air to the outside. Conversely, when the vents are not in use, cold air infiltrates the building through the vents.

It is likely that the vent with the greatest influence is the direct fresh air vent (600 × 600 mm in the west vestibule feeding air into the kitchen above the refrigerators). This vent is manually controlled and supplies a

great amount of fresh air to the building, as well as make-up air for any combustion devices (such as the stove and furnace). A heat exchanger may be useful for regulating this vent.

Doors

The IR imagery shows heat loss around both the east and west vestibule exterior doors, likely from wear on the door seal, as well as through the window. Both of these doors are insulated residential doors with a viewing window in the upper half of the door.

Windows

The exterior IR imagery of the building taken on the south side in the vicinity of the large fixed window clearly showed little temperature variation at the quad-paned window location.

The exterior IR imagery of the double-paned windows showed more heat loss than found for the quad-pane window. This is seen in the IR imagery in Figure S-3, showing the southern exterior side of the building. A well sealed opening during the installation of higher quality windows maximizes the anticipated energy savings. In addition, installing and sealing the window opening are important so as not to compromise the energy savings from the higher quality window.

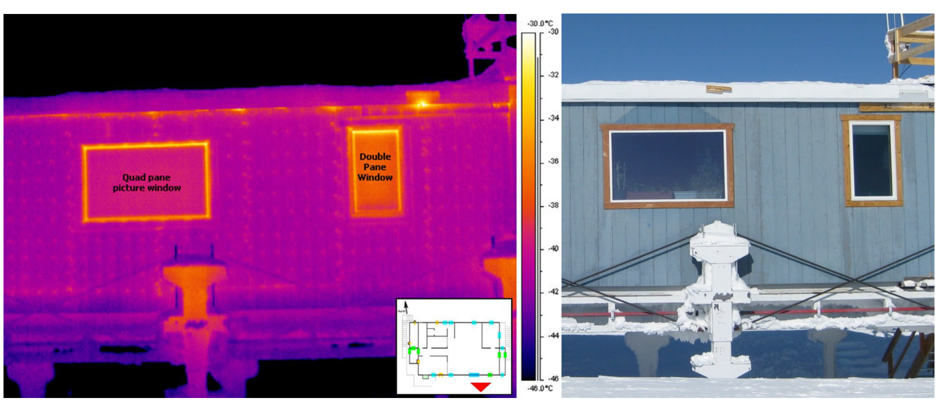


Figure S-3. Quad-pane window reduces heat loss compared to a double-pane window (exterior south side).

Roof

The IR imagery showed modest heat loss through the roof members over the main building; this is not considered a big contributor.

The access hatch to the roof penetrating the ceiling in the unheated east vestibule is a source for heat loss and creates a buildup of frost along the interior of the opening. Heat sources are the shared wall with the main room, and the sunlight that comes through the southern window.

Relocating the roof access hatch into an unheated vestibule was a sensible modification. The large size (76 × 91 cm) of the penetration through the ceiling and roof in the main room would be difficult to seal to minimize heat loss. The previous opening, where the old roof access hatch was located in the ceiling of the main room, is well sealed. No cold air infiltration was observed from inside the Big House at the old access hatch location.

The radome on the roof was not observed to be a significant contribution to heat loss. However, there is some heat loss from the inside of the Big House where the cables run through the ceiling up into the radome.

More heat loss was observed in the IR imagery from inside and outside the Big House at the roof line, where the rafter beams connect to the wall SIP at the joint locations, compared to the wall system.

Similarly, more heat loss was observed along the south side fascia, particularly toward the eastern end of the building, where instruments had previously been installed and in locations where repairs had been made to the metal flashing. Figure S-4 illustrates the heat loss observed in the IR imagery from the south side eastern end of the building. The cable pass-through to the radome (Fig. S-5) is an example where the cable pass-through is well insulated and little heat loss occurs.

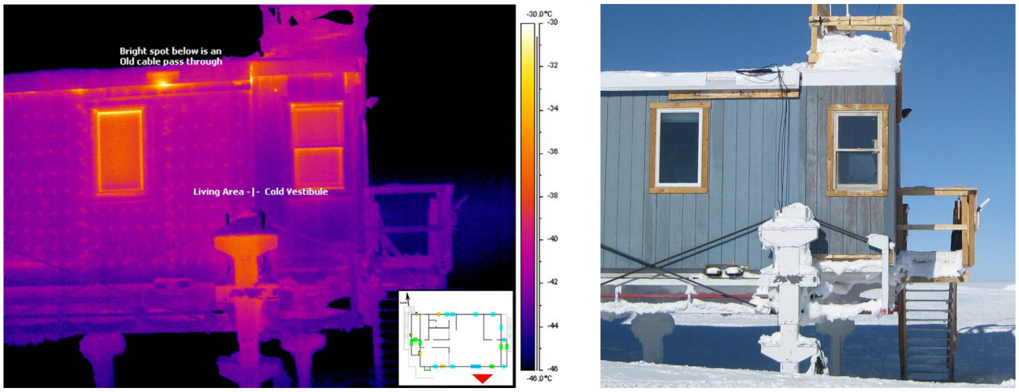


Figure S-4. Difference in thermal envelopes between heated main room and unheated east vestibule, and heat loss along fascia (exterior south side).

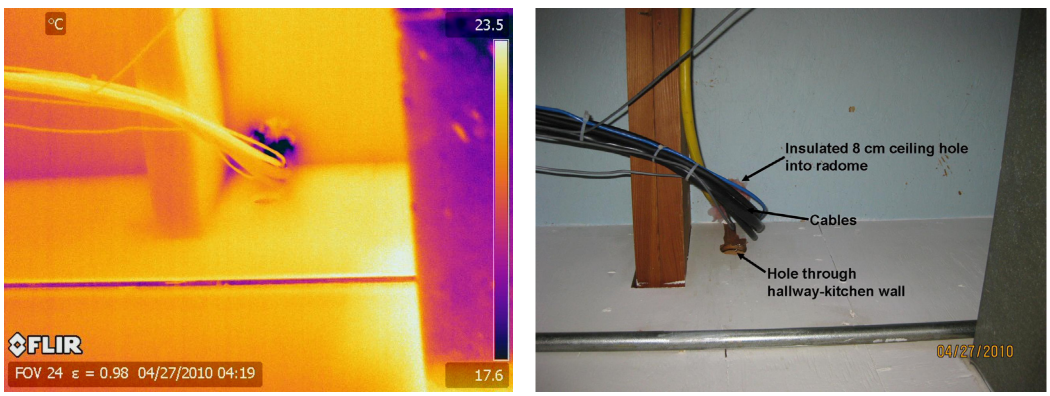


Figure S-5. Well insulated cable pass-through into radome.

Walls

IR imagery collected from the exterior of the building indicated that the joints between the SIP joining the wall panels leak little air, suggesting that the joints continue to perform well and do not show signs of stress resulting from lifting the building.

On the main floor, where the wall is joined to the deck, several areas were identified. Locations that appeared to have more heat loss included a cold spot under the counters in the main room, as shown in Figure S-6 (which was immediately caulked), an area in the northeastern corner of the office (which may not be noticeable owing to storage under the desk), and a location in the bathroom along the baseboard where frost had developed.

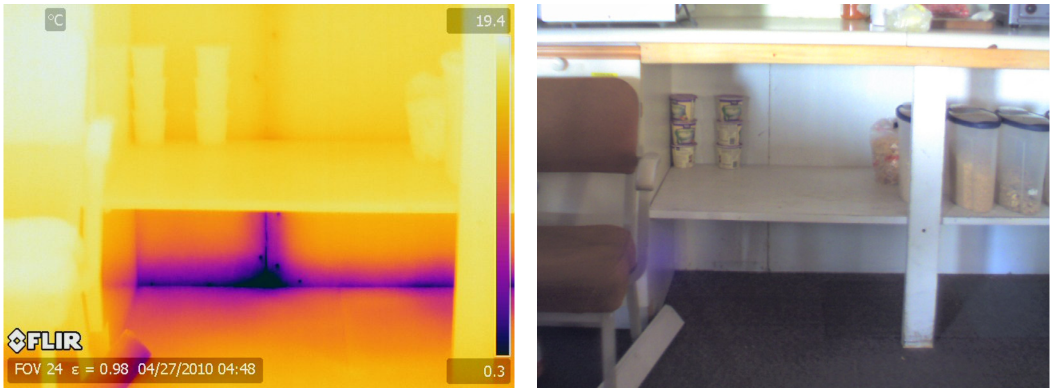


Figure S-6. Cold spot under the counter in the south wall of the main room.

Very high heat loss was observed at the southwestern corner of the structure where the west vestibule connects to the main building (Fig. S-7). This location was identified and noted for repair when the penetration survey was conducted by CPS.

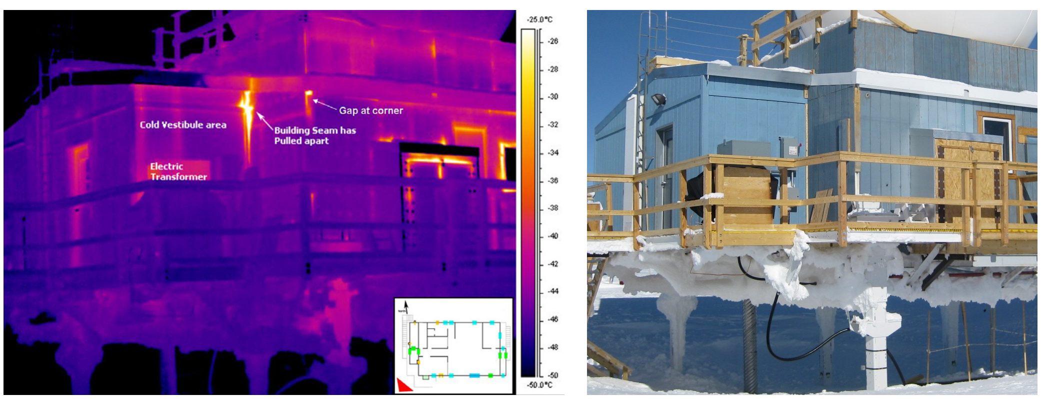


Figure S-7. Excessive heat loss at a gap located in the southwestern corner.

Base

The IR imagery of the exterior base of the structure did not show significant heat loss through the floor. Other than open active vents, the blocked-off vent in the floor of the mechanical room was the only bright spot in the IR imagery. Several pieces of loose sheathing on the underside of the building should be reattached.

Recommendations for mitigation

The following recommendations are provided for the Big House to address the areas where heat loss was indicated from the IR survey:

- Repair the vent in the laundry room to operate effectively, possibly through the use of an automated system, in removing warm moist air from the clothes dryer from inside. Yet, when it is not in operation, it is securely closed with cold climate dampers.
- Use durable exterior hardware should to ensure a proper seal. A direct vent in the north wall of the laundry room created a pathway for cold air infiltration. This vent was removed and the hole insulated and sealed during the 2010 summer season. For through-wall vents, durable exterior hardware should be used to ensure a proper seal when the vent is not in use. Another possible solution would be to relocate this vent to an internal location, such as the wall between the laundry room and scullery, or the wall between the laundry room and hallway. Either of these locations would serve to move this warm, moist air within the Big House to disperse the humidity where it is needed into the main room, and this would also alleviate the ice buildup on the north exterior wall.
- Replace the remaining double-paned windows with triple-paned windows. This will improve the energy efficiency. This task has been identified and planned by CPS for improvement.
- Continue to periodically locate and seal up areas where cold air infiltrates into the building.
- Prevent cold air leakage into the building via the stove vents, so appropriate dampers for them should be explored.
- Reduce heat loss around the exterior doors in both the east and west vestibules by replacing the seals.
- Remove the windows in the east vestibule if they are not necessary. This will reduce moisture buildup. Another method to reduce the amount of moisture buildup in arctic entryways is to maintain a constant low temperature (between 2 and 5°C) to mitigate the large temperature swings in an unheated vestibule.
- Reduce heat loss through building envelope transitions, such as doors and windows. While windows and doors are essential to the function of a building, they create discontinuities in the building envelope and reduce the thermal resistance of the wall system. Heat loss through

building envelope transitions is mitigated to some extent with good frames and installation procedures.

- Allow more air leakage through exterior entryway doors to vestibules. The entry way doors in the Big House are scheduled to be replaced with freezer doors. A standard and effective arctic entry design locates entryway doors with the tightest seal closest to the warm side of the building. This design recommends that exterior entryway doors to vestibules allow more air leakage. The tight seal created between the main building and the vestibule, by installing the freezer-type doors here, would reduce heat loss and keep moisture out of the vestibule. Conversely, installing freezer-type doors at the exterior entryway, further away from the warm side of the building, would trap moisture. Keeping the type of exterior vestibule (arctic entry) doors currently installed, moisture can escape as these doors are not as airtight as the freezer doors.
- Replace the seals of freezer-type doors regularly. The Green House has freezer-type doors installed but with some damage to the seals. Regular replacement of the seals, such as annually, would maintain the working condition of the doors.
- Repair the two gaps on the southwestern side of the building, at the interface where the west vestibule connects to the main building and the gap at the southwestern corner.
- Test the air tightness of the Big House using a blower door test.
- Use an IR camera following a lift of the Big House to detect any areas of the building where the thermal envelope may be compromised.
- Develop a formal procedure to seal up penetrations to reduce energy loss, where openings for cables penetrate the building and especially where cables have been removed.
- Consider locating cables that penetrate through the building envelope, and connect to outside sensors, through a common access conduit in a designated location that may be sealed to keep cold air out.

1 Introduction

The Big House at Summit Station, Greenland, is the main facility supporting overall station operations, providing common areas for dining, washing, and leisure for camp attendees and staff. The Big House has served in this capacity since its construction in 1989. As the National Science Foundation (NSF), and its operations contractor CH2M Hill Polar Field Service (CPS), considers the long-range plan for Summit Station, the current condition of the Big House requires evaluation.

Personnel from the U.S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (ERDC-CRREL) visited Summit Station from 24 to 29 April 2010 to conduct an infrared (IR) survey. Thermography is a useful tool for quickly and easily identifying variations in the thermal properties of buildings that result in temperature changes. Deficiencies ascribable to inadequate insulation, drafts, or damage from moisture, which otherwise may not be readily identified with the naked eye, are revealed through IR images. In the case of the Big House, disturbances that have resulted from lifting the building were also considered.

The problem

The Big House, as it is currently used, may be phased out over the course of the next few years once new structures are in place at Summit Station. An engineering assessment of the Big House building and its current condition can aid in determining two things: 1) current building deficiencies that could be addressed to increase energy efficiency in the short term, and 2) potential structural improvements and rehabilitations that could be made to increase its longevity, reduce maintenance needs, and enable its use for other purposes.

Project objective

This study identifies existing deficiencies in the Big House that may reduce the energy efficiency and structural deficiencies that may be improved to increase the building's service life.

Project scope

NSF and CPS provided background information on the history of changes and lifting done to the Big House in recent years. Infrared and visual surveys were conducted by on-station CPS personnel and ERDC-CRREL during a field visit. These were combined with a survey of penetrations through the building envelope.

2 Background

Summit Station

Located at the apex of the Greenland Ice Sheet, Summit Station is a year-round science camp supporting atmospheric research conducted in the extreme and hostile arctic environment. The camp is situated above the Arctic Circle at 72°34' north; 38°28' west, at an elevation of 3230 m. Access to this remote science camp is via ski-equipped LC-130 aircraft, which is also the primary means of carrying cargo, equipment, and fuel. The landing strip (or skiway) is located on the western side of the camp. The infrastructure at Summit Station consists of berthing modules, a shop–power plant facility, and temporary structures that accommodate research projects. The main administration building located at Summit Station is known as the "Big House" (Fig. 1).

Figure 1. View of Big House (29 April 2010).

The Big House is the main building for the office and houses common facilities for camp staff and attendees. A floor plan is shown in Figure 2. The building is roughly 17 × 8 m with entry vestibules at both the east and west ends. Within the building is the main communications office, a kitchen for

food preparation and serving, a scullery for washing dishes, a refrigeration room, commonly called the “freshie shack,” to store perishable food, and a large common area for dining and leisure. There is also a washer/dryer for laundry, a single flush toilet, and shower. Heat and water are supplied from the systems located in the mechanical room, which houses an oil-fired furnace, a 1500 L-water storage tank, a hot water tank, and pressure tank.

The Big House was constructed on a permanent snow field. The structure is elevated above the snow surface on 10 steel columns, connected by steel trusses under the building (Curtis and Tobiasson 1991). The columns allow for the periodic, and necessary, lifting of the building to maintain it above the snow surface to guard against completely being drifted in. Consequently, the timber footings originally placed in the processed snow foundation are now approximately 18 m below grade (CPS and NSF 2009; Curtis and Tobiasson 1991).

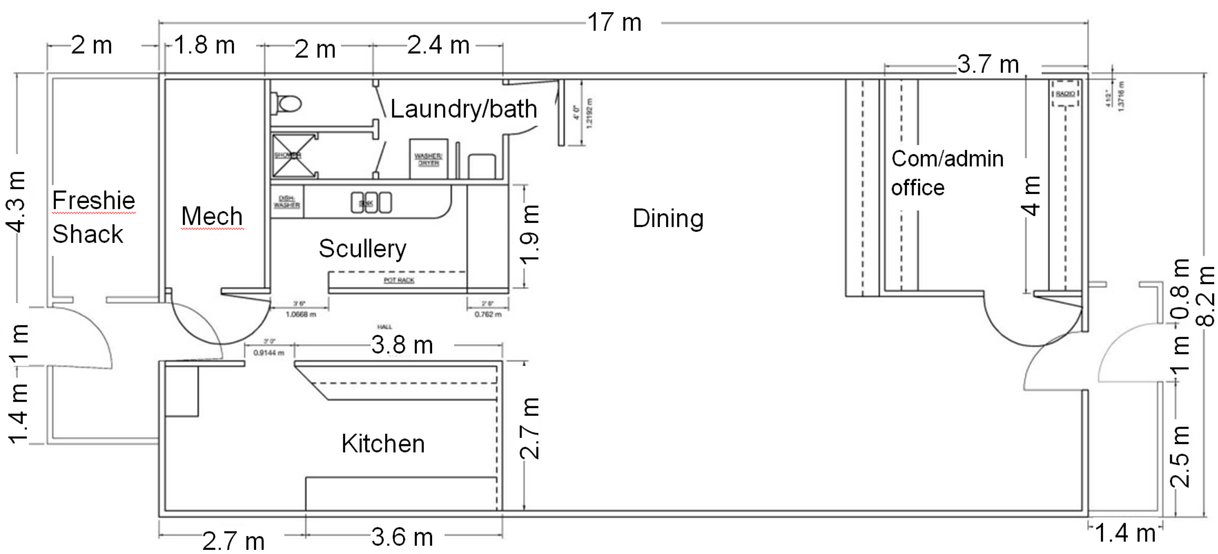


Figure 2. Plan view of Big House (modified from CPS [2010] Big House Floor Plan).

Arctic structures

In 1959–1960 two stations were built as part of the U.S. Air Force Distant Early Warning (DEW) Line project (Osgood and Bornstein 1989). Both of these stations were massive structures, elevated above the snow surface, and required periodic lifting. While the design life was 10 years, they remained operational for 30 years until they were abandoned in the early 1990's (Curtis and Tobiasson 1991).

NSF has sponsored research in the Arctic for a number of years. In Greenland, one of the earlier projects was the Greenland Ice Sheet Project (GISP1) that began in 1979. GISP1 provided early experience with constructing and operating facilities in the unique arctic environment. Prior to the closing of the DEW Line and GISP1 stations, plans were underway for the design of GISP2, which was further north on the Greenland Ice Sheet, well above the Arctic Circle where Summit Station is currently located (Curtis and Tobiasson 1991).

Since 1959, much experience has been gained in designing, operating, and maintaining structures in the uniquely challenging arctic environment. The design life for a semi-permanent structure at GISP2 was 5 years to provide support for an ice core drilling camp collecting ice cores at the summit of the Greenland Ice Sheet (Tobiasson unpublished). During the busy summer season, the design population of the camp would be up to 40 scientists, technicians, and support staff.

Accepted practice for Arctic design

Ventilation

Proper ventilation to maintain good indoor air quality is important in cold regions. Cold air is unable to hold much water and this may create an excessively dry and uncomfortable indoor environment. Inadequate humidity can lead to static buildup, which is detrimental to electronic devices (Freitag and McFadden 1997). However, to prevent heat loss, uncontrolled air infiltration must be limited to suitable vent openings through the building envelope.

Vestibules

The use of transition rooms between the outdoors and the warm interior of a building in cold regions is an important design feature. Otherwise known

as “Arctic entries,” these vestibules minimize the intrusion of cold air into the main building from the outside and heat loss from the main building (AIA Alaska 2004; Freitag and McFadden 1997). The vestibule also provides a location to shed snow from bulky coats and boots before entering the building. Because warm air rises and cold air sinks, lowering the height of the arctic entry takes advantage of this by further reducing mixing the cold and warm air (AIA Alaska 2004).

Windows

While windows (and doors) are a primary example of high heat loss areas, they are necessary for safety, as well as quality of life of the occupants. Despite their heat loss, high quality windows are available, and, if installed correctly, can reduce the amount of heat loss from the building (Freitag and McFadden 1997).

Thermal bridges

Different materials that compose the building envelope are in contact with one another and may create pathways for heat loss. These are called “thermal bridges.” The selection of materials, including the type and location of the vapor barrier, and the construction techniques used are critical to reducing or eliminating the ability of the cold to penetrate through the building envelope. Thermal bridges may cause moisture buildup, icing, and, potentially, issues related to mold or mildew.

Climate conditions

At the summit, the thickness of the Greenland Ice Sheet is about 3048 m (Curtis and Tobiasson 1991). The ice sheet moves at a rate of roughly 1.6 m/year to the west. The average temperature ranges from a high of −22°C during the summer to −46°C during the winter. With the wind chill factored in, it is not uncommon to experience temperature lows of −54°C. The summer season, from May to August, experiences 24 hours of daylight, while October through March, or the winter season, experiences complete darkness. April is the spring transition month, as the daylight time grows longer, and September is the transition to winter, as the nighttime hours increase until total darkness is reached (CPS 2009). While the annual snowfall is only 65 cm, the accumulation via drifting and blowing snow, with the prevailing wind blowing from the south, is significant and an issue for permanent structures.

Brief history of changes

The following summary of the history of the Big House is compiled from the notes collected during a teleconference among NSF, CPS, and ERDC-CRREL personnel in November 2009. This call established the knowledge base of the history of changes to the Big House since it was first constructed. This information aided ERDC-CRREL's organization of the IR survey.

The foundation and structural support members were constructed in 1989. The building was constructed the following summer, in 1990. The original exterior consisted of 127-mm structural insulated panels (SIP), with 12.7-mm stressed oriented strand board (OSB) skins (CPS 2009b; Tobiasson unpublished) and 100 mm of high-density isocyanurate insulation (Tobiasson unpublished; Anderson 2010). Fairly early on, an entry vestibule was added on the eastern side of the building where, in 2008, the roof access hatch was relocated. In 1999, the exterior was re-sheathed with 38-mm expanded polystyrene (EPS) insulation and 12.7-mm T-111 siding, which was attached with a number of fasteners. The wall thickness is 178 mm (Fig. 3). In 2006, a vestibule was added to the western end of the building, where the freshie shack and dry storage are located. It is believed that both the roof and floor are original construction. The roof is 229 mm thick, consisting of a 127-mm structural stressed skin SIP, 89 mm of foam insulation, and 13-mm rigid panel, all covered with steel roofing (CPS 2009b).

The building has been lifted on four occasions: 1999, 2005, 2008, and 2010. The gross lift for each of these was 2.1 m, approximately 4.5, 4, and 4.5 m, respectively. The steel columns are 254 × 254 mm, and in 2008 were spliced to the existing 127 × 127 mm columns to improve the support. The process of lifting the structure, prior to 2010, required each column to be lifted individually. In 2010, a new hydraulic lift system was designed and used that lifted the entire structure at once. It is expected that lifting the structure as one entity will reduce the amount of racking of the building.

Figure 3. Big House wall material types and thicknesses.

The mechanical room houses the main systems in the Big House. The building is heated primarily by a fuel-oil-fired furnace, originally installed in 1990. The fuel tank sits outside on the deck on the eastern end of the building and the fuel line runs on the underside of the building to the furnace. The water supply in the Big House comes from melted snow (melted by waste heat in the garage shop), transported and then pumped into the 1514-L storage tank in the mechanical room. Prior to use, water is UV treated and pumped via a pressure tank to the kitchen, scullery, and laundry room/bathroom system. Hot water is provided by a 151-L electric tank. All waste water is eliminated from the building through a gravity-driven, insulated sewer outfall pipe drilled roughly 9 m into the snow. Power is supplied to the Big House via an electric cable buried beneath the snow surface. Six electric heaters were installed in 2009 to provide back-up heat.

Changes and upgrades to the Big House factor in the need to continuously improve energy efficiency. Currently, the station operates primarily on diesel power. In 2008 a 6-kW wind turbine was installed to pilot the use of renewable energy at Summit Station and reduce the use of fossil-based fuel (Baring-Gould and Roberts draft). Currently, the furnace uses approximately 3028 L of fuel annually to heat the building (Fig. 4). Within the

Big House, improvements have been made over the years to increase the energy efficiency of the building and reduce the amount of fuel needed. Examples include installing a large, fixed, quad-pane window (Armstrong 2010) in the southern wall of the main room, annual inspection and replacement of the weather stripping around doors and windows, and efforts to seal penetrations to eliminate air infiltration.

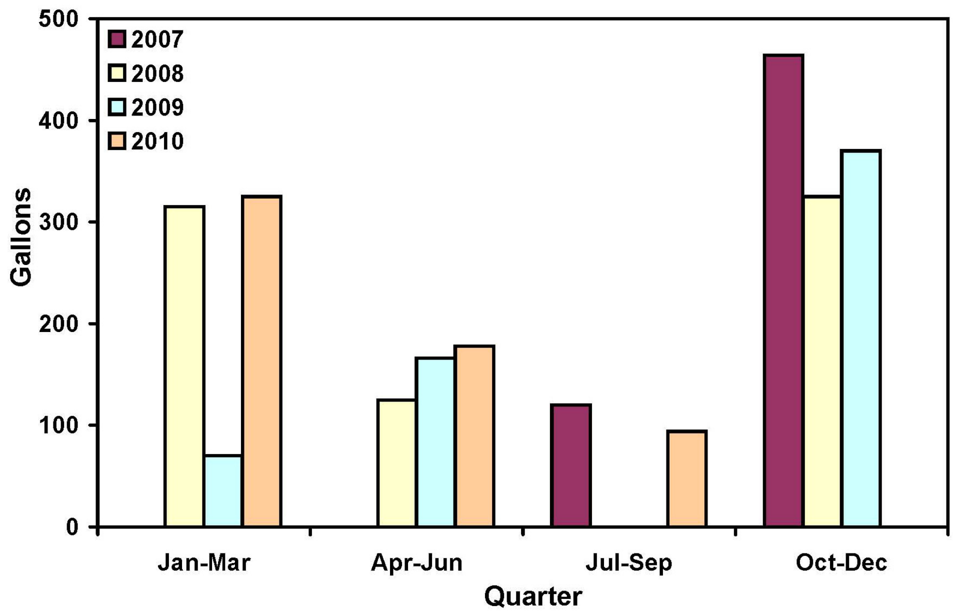


Figure 4. Big House quarterly fuel usage from July 2007 through October 2010.

3 Technical Approach

CPS conducted an initial IR and visual survey during winter 2009–2010 to identify initial problem areas, and compiled an extensive list of penetrations through the building envelope (Appendix A). ERDC-CRREL visited Summit Station from 24 to 29 April 2010 to continue the IR and visual survey. Indoor temperature and relative humidity (RH) data were also collected.

Indoor temperature and relative humidity measurements

During the ERDC-CRREL field visit, indoor temperature and RH measurements were collected in the Big House using four dataloggers positioned at various locations within. The dataloggers are ACR Systems, Inc., SmartReader 2 devices (www.acrsystems.com). The temperature sensor is a thermistor with an accuracy of ±0.2°C over a range of 0 to 70°C, while the RH sensor consists of a "capacitive thin polymer film" with an accuracy of ±3% from 10 to 90% within a temperature range of −20 to +40°C (ACR Systems, Inc. 2010). The units were calibrated in March 2010. The ACR dataloggers operate off of a lithium battery, are moderately priced, are small and light, and are also simple to program and operate. They were programmed to read at a 1-minute frequency.

In general, the dataloggers were affixed to the wall where they would not be disturbed and not be affected by drafts. In the main room and the kitchen, they were located approximately 1.5 m from the floor. Both of these locations were monitored continuously throughout the field visit. The remaining two dataloggers roamed, meaning they were set in initial locations (the west vestibule and mechanical room) for a time and then relocated (to the east vestibule and laundry/bathroom) after 24 hours to collect data in as many locations as possible. In all, temperature and RH measurements were collected at six locations. The locations of the dataloggers are shown in Figure 5.

a. Main Room

b. Kitchen

c. Mechanical Room

d. Laundry Room / Bathroom

e. West Vestibule

f. East Vestibule

Figure 5. Sensor locations to collect indoor temperature and relative humidity data.

In the main room, the datalogger was positioned near the thermostat. This is the same location where CPS personnel placed a temperature sensor to

collect indoor data during February–March 2010. The location in the kitchen was on an interior wall, roughly 0.6 m from the doorway opening. In the mechanical room, the datalogger was located on the wall separating the mechanical room from the freshie shack, above the water storage tank. In the laundry/bathroom area, the datalogger was positioned above the light switch. In the west vestibule, the datalogger took advantage of an existing fastener, on which the datalogger was hung with a piece of string. The datalogger did not rest directly on the surface; there was an air gap between the unit and the plywood fresh air vent. In the east vestibule, it was located on an exterior wall next to the main exterior door.

Both the main room and kitchen dataloggers remained in place after the ERDC-CRREL field visit and continued to collect data at a 5-minute interval. This was coordinated with CPS to continue data collection through the summer 2010 season.

Infrared survey

An IR survey was conducted of the exterior and interior of the Big House to identify locations of heat loss. Initially, 25 positions were marked in a clockwise direction around the exterior of the building. The views overlapped to ensure full coverage. Additionally, images of both the roof and base of the building were collected. Visual images were collected at the same locations as the IR images to identify the actual features present when reviewing the IR imagery. As there was a fair amount of overlap in the initial 25 positions, 11 views were selected for discussion in this report. On the website, 14 views are presented and discussed.

Two types of thermal imaging cameras were used to complete the survey: a ThermaCAM S-60 and SC 640. Both were manufactured by FLIR® and are classified as cameras suitable for research and development. Both cameras have lower limit temperature capabilities, down to −40°C, and both have a standard 24° lens. The S-60 also has a 45° wide-angle lens, which was used during imaging of the Big House. The IR image file size of the S-60 is 320 × 640 pixels, while the SC 640 is larger at 640 × 480 pixels. Both IR cameras are ganged with a digital camera and take a visual image at the same time as the IR image. However, the digital camera is of rather low quality; therefore, the visual images were taken with a Cannon PowerShot.

To minimize the effect of solar loading to the exterior surfaces of the building, exterior images were collected after sundown, roughly between 2130 to 0400 hours. Some light remained in the sky during this time, as the sun does not fully set to reach darkness above the Arctic Circle at this time of year. Heat gain from exposure to sunlight during the day can influence the IR images and, therefore, it is best that no sunlight be on the surfaces planned for imaging (FLIR® 2009).

A companion website to this report is available at: (http://www.crrel.usace.army.mil/sid/SummitGreenland/)

4 Results

Introduction

The results of ERDC-CRREL's field visit from 24 to 29 April 2010 are included in this section. Temperature and RH data are presented, along with a selection of the exterior and interior IR and visual images. The images were chosen to illustrate the existing condition of the Big House thermal envelope. The images include the exterior walls, roof, and base of the structure. The information collected during this period provides a snapshot of the Big House.

Temperature data only were collected during the winter (2 February to 3 March 2010), while both temperature and RH data were collected during the spring (24 to 28 April 2010) and summer (28 April to 21 August 2010). Table 1 summarizes the temperature data collected during the winter. The winter temperature data were collected every 5 minutes. The sampling frequency of the spring data was 1 minute, and the summer season frequency was 5 minutes. The partial vapor pressure was calculated using the temperature and RH measurements. Table 2 summarizes the temperature, RH, and calculated partial vapor pressure for the spring and summer.

Table 1. Summary of temperature measurements for the main room collected between 9 February and 2 March 2010 (winter).

Main Room		
	Data start	2/9/10 08:38hr
	Data end	3/2/10 17:08hr
	Duration (hours)	512.5
Temperature (°C)	Maximum	27.5
	Average	19.3
	Minimum	17.5
Location		1.5-m height near thermostat

Temperature and relative humidity measurements

The temperature and RH data are useful for demonstrating the effects of population size on building usage. The greater the number of people who are on station, the higher demand is for the use of the facilities in the Big House. More people translate into more cooking, laundry, and bathing, and more people inside the building. All of these increased demands generate more heat and moisture within the building, making it, at times, an uncomfortable environment. Regulating the interior temperature is difficult and often windows are opened in an attempt to cool it down.

The station population during the field visit reached 29, as the station was preparing to open for the 2010 summer season. This was an increase from the 5 people on station during the previous operational phase (third winter phase). The station is designed to support 40 scientists, technicians, and staff. While the population normally remains around 40, it sharply increases, for a short period, to as many as 50 during the height of research and operations activities. Population numbers, provided by CPS, since 2005 for Summit Station are shown in Appendix B.

Weather data, including air temperature and RH, are continuously collected at Summit Station through the National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (CMDL) (http://www.esrl.noaa.gov/gmd/). The indoor temperature measurements collected between April and August for both the main room and kitchen are plotted with the outdoor temperatures in Figure 6. Figure 7 shows the temperature measurements collected for all of the interior locations during the field visit from 24 to 28 April 2010.

Figure 6 shows a trend of increasing outdoor air temperature. Inside the Big House, both the main room and the kitchen shows sinusoidal temperature changes that coincide with the times during the day when more (warmer environment) or fewer (cooler environment) people are inside, or when food is being prepared in the kitchen. It is probable that the times when the temperature drops significantly (i.e., overnight of 12 May 2010) correlate to windows (one or more) being left open and too much cold air entering the building. Likewise, the high temperature readings in the kitchen are caused by cooking, where the stove vents alone cannot exhaust enough air to cool the room.

In general, the range of temperature readings is similar among the summer months (April to June). This was also true during the field visit (April), as shown in Figures 6 and 7, respectively.

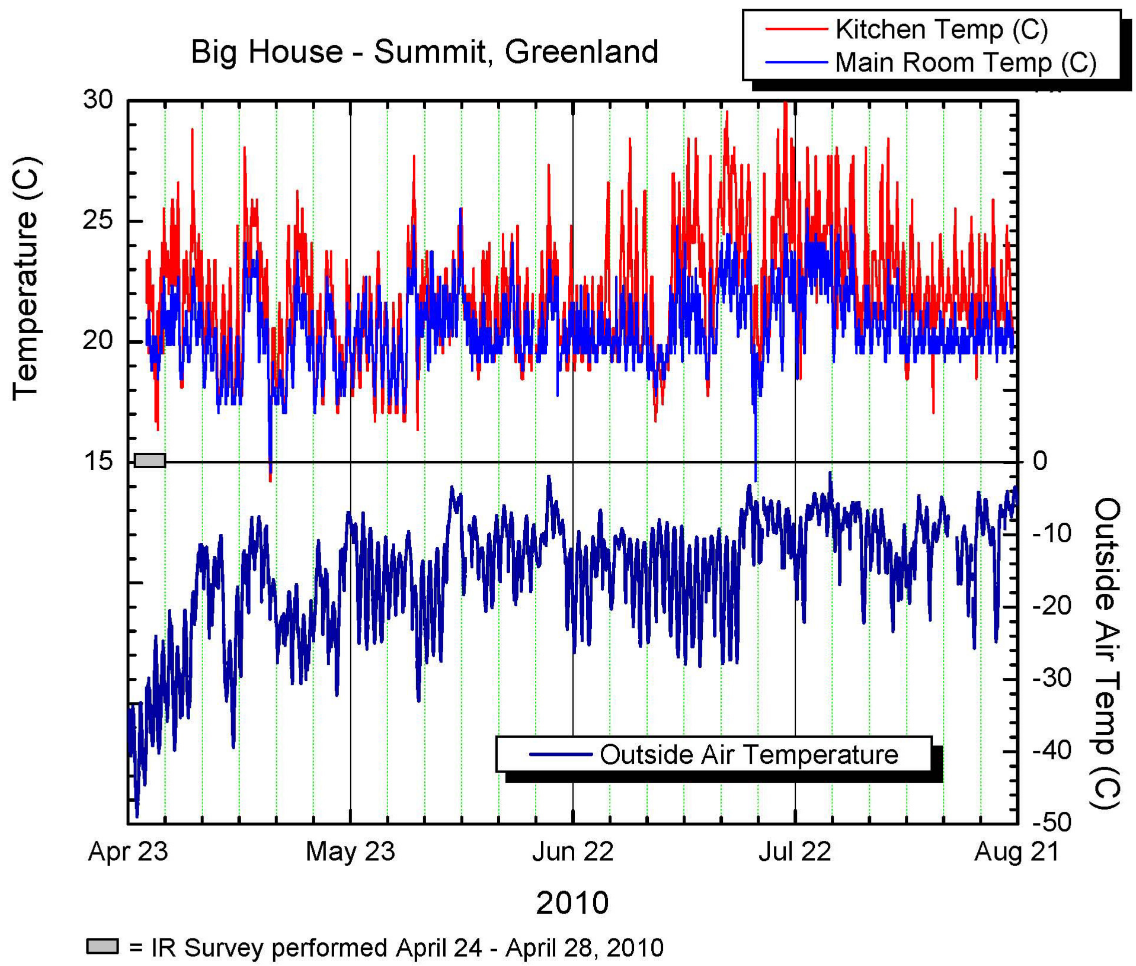


Figure 6. Air temperature measurements for the Big House main room and kitchen interior rooms, and outdoor readings from April to August 2010. The difference between the temperatures of the main room and the kitchen was on average 1.4°C, with the kitchen being warmer. The maximum difference between the kitchen and main room was 2.5°C (kitchen being warmer) and the minimum temperature difference was −3.5°C (kitchen being cooler than main room).

Table 2. Summary of temperature and relative humidity measurements, and calculated partial vapor pressure, at all interior locations for spring and summer.

		Main Room	Kitchen	Mechanical Room	Laundry / Bathroom	West Vestibule	East Vestibule
SPRING							
	Data start[1]	4/25/10 11:25hr	4/25/10 11:25	4/25/10 11:34	4/27/10 1:00	4/25/10 11:55	4/27/10 1:00
	Data end	4/28/10 07:09hr	4/28/10 7:09	4/27/10 1:00	4/28/10 7:20	4/26/10 11:03	4/28/10 7:12
	Duration (hours)	67.8	67.7	37.4	30.3	23.1	30.2
Temperature (°C)	Maximum	22.7	25.5	22.0	25.2	-1.2	13.5
	Average	20.2	21.6	20.4	20.1	-7.5	-4.9
	Minimum	18.5	16.4	18.5	18.1	-12.3	-15.5
Relative Humidity (%)	Maximum	52.3	47.2	39.6	80.0	100	100
	Average	30.8	26.2	23.2	37.0	73.0	76.0
	Minimum	17.3	15.0	11.8	15.2	47.0	31.4
Vapor Pressure (Pa)	Maximum	2,088.6	1,544.7	1,502.1	2,092.6	1,326.7	995.1
	Average	693.5	681.4	566.0	882.0	305.4	343.6
	Minimum	207.6	284.3	288.1	412.5	98.7	102.1
Location		1.5 m height (near location Cmdr put Hobo) and near thermostat	1.6 m height; 0.6 m from doorway opening (near the mixer)	1.9 m above floor on West wall near water tank; 1.8 m from doorway	Approximately 1.5 m above floor on wall between bath stall and shower stall	Reset to 1.5 m above floor 0.3 m from 'old exterior' on plywood fresh air vent	East wall ~1.8 m above floor next to exterior door

SUMMER							
		Main Room	Kitchen	Mechanical Room	Laundry / Bathroom	West Vestibule	East Vestibule
	Data start[2]	4/28/10 09:19hr	4/25/10 11:25	Data not collected for these locations during summer season			
	Data end	8/20/10 23:58hr	4/28/10 7:09				
Temperature (°C)	Maximum	25.5	29.9				
	Average	20.3	21.6				
	Minimum	10.3	9.5				
Relative Humidity (%)	Maximum	72.5	56.0				
	Average	28	23.8				
	Minimum	8.7	8.6				
Vapor Pressure (Pa)	Maximum	2,088.6	2,079.5				
	Average	678.7	627.8				
	Minimum	180.6	163.5				
Location		1.5 m height (near location Cmdr put Hobo) and near thermostat	1.6 m height; 0.6 m from doorway opening (near the mixer)				

[1] Readings collected during the spring field visit (23 to 28 April) used a 1-minute frequency.

[2] Readings collected during the summer season (28 April to 21 August) used a 5-minute frequency.

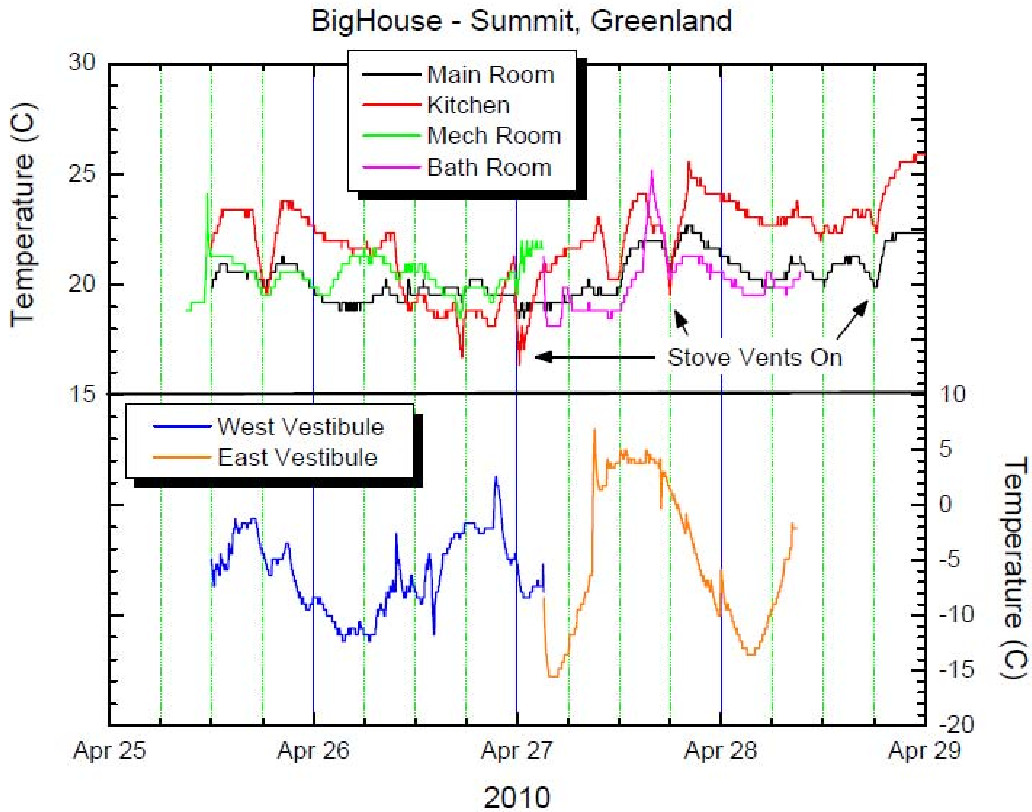


Figure 7. Temperature measurements for the Big House interior locations during field visit 24 to 28 April 2010.

The interior temperatures (Fig. 7) for the main room, kitchen, laundry/bathroom, and mechanical room track each other reasonably well. As expected, the greater temperature variations occur in both of the vestibules. The temperatures measured in the west vestibule are more moderated, as this sensor was positioned on an interior wall. In the unheated east vestibule, the sensor was located on an exterior wall (Fig. 5). Both the solar gain from the sun once it rose and the solar gain through the southern window contribute to the temperature fluctuations. Entrance locations are a significant source of heat loss in buildings in cold regions when doors are being opened and closed (Freitag and McFadden 1997).

The temperature in the main room fluctuated by 1 to 2°C because of the number of people present, and heat movement from other locations, such as the kitchen, and laundry room (from showering and operation of the clothes dryer). Comparing the measurements collected in the interior portions of the Big House, we found the trend for the kitchen measurements to be warmer. The exception to this was when the stove vents were operating during food preparation. Figure 7 shows that the drop in temperature around midnight of 27

April occurred when the stove vents were turned on for the IR survey to observe the impact of heat being drawn out of the Big House from the vents.

Average 15-minute temperatures are compared over a 28-hour period for the main room (winter and spring) and kitchen (spring) in Figure 8. "Zero" on the *x*-axis corresponds to 0900 hours for each room. For the main room, both the winter and spring temperatures are similar, although the station population increased from 5 to 29.

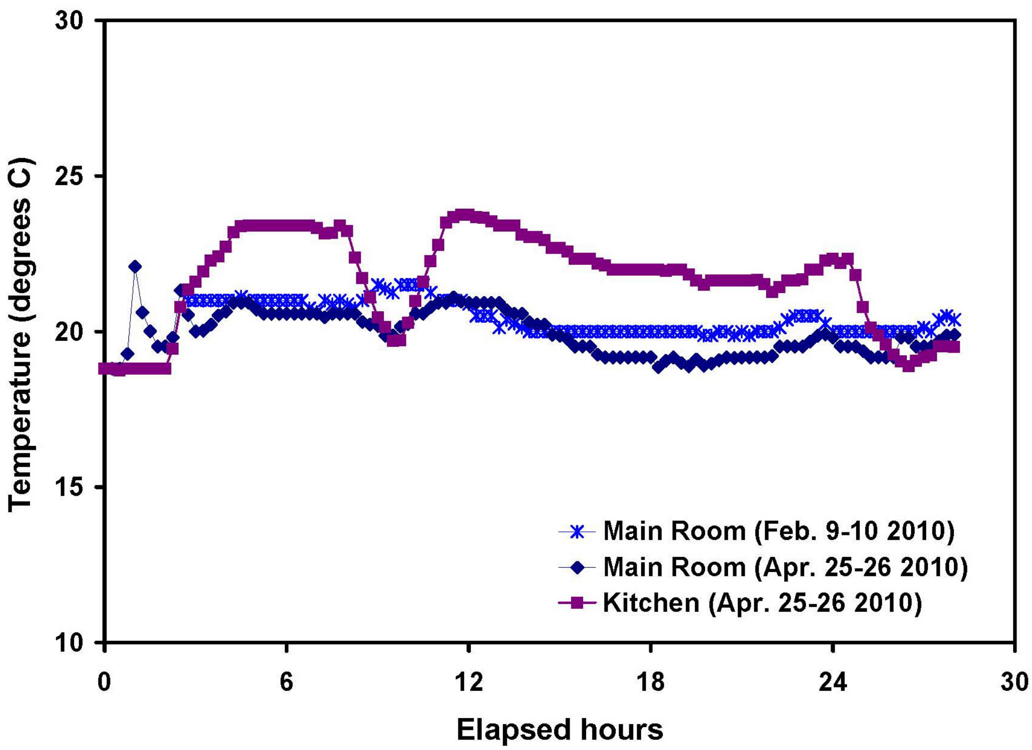


Figure 8. Temperature measurement comparison of the main room during winter and spring. Temperature readings were aligned beginning at 0900 hours (0 elapsed hours).

Relative humidity

Cold air holds less moisture than warm air, and, as a result, becomes saturated at a much lower temperature. Relative humidity is the amount of moisture a volume of air can hold at a given temperature, expressed as a percentage (FLIR® 2009). Figure 9 compares the outdoor and indoor (main room and kitchen) RH for the Big House during early summer. The outdoor readings show variability, as would be expected. The indoor RH readings also fluctuate, and indicate a relatively tight building.

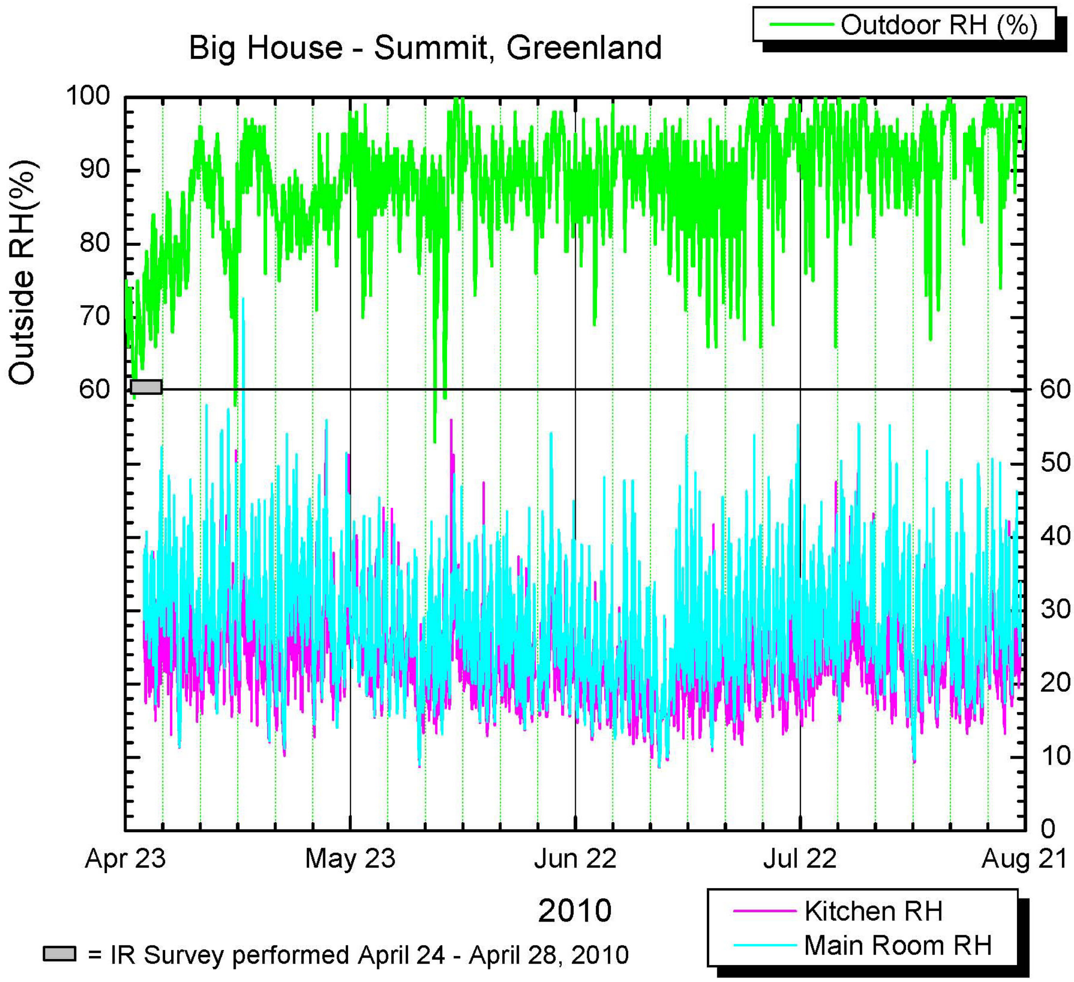


Figure 9. Outdoor and indoor relative humidity measurements from April to August 2010 (early summer).

In cold climates, indoor air quality is important for health, as well as for comfortable living conditions. Too little moisture in the air causes a build-up of static electricity that can be damaging to sensitive electronic devices, such as computers. Humidity levels that are too high in the air may cause moisture buildup (Freitag and McFadden 1997). Changes in the humidity levels may be attributable to the number of persons within the space or increases in water vapor from cooking, showering, or laundry. Figure 10 shows the measured RH in the Big House from 25 to 29 April 2010: the RH for all of the interior locations (main room, kitchen, laundry/bathroom, and mechanical room) ranged from 12 to 79% during the last week of April. Overall, the RH values for these rooms tracked each other, with the exception of a couple of spikes in RH in the laundry room, likely during times when either the shower or clothes dryer were operating. There are two vents on the north wall

in the laundry room (one that vents directly out of the building, the other that connects to the clothes dryer) that did not properly expel warm, moist air out of the building, instead venting it within.

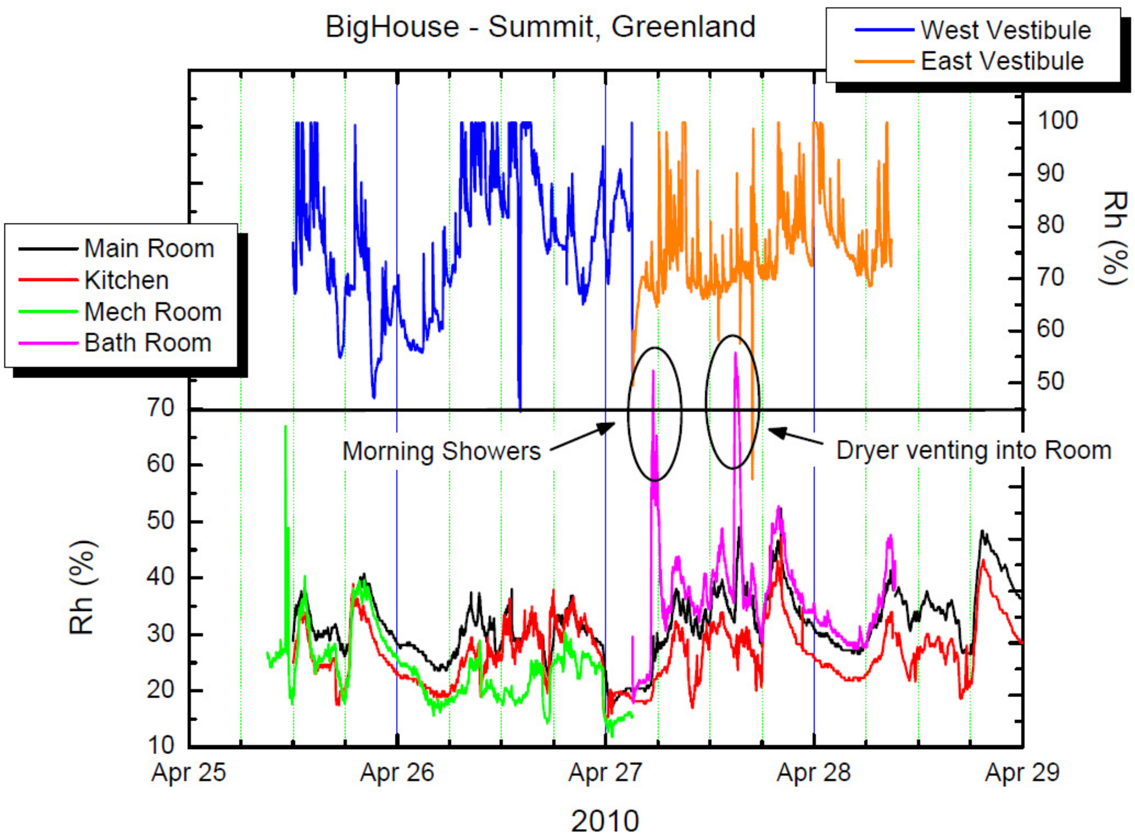


Figure 10. Relative humidity measurements of all interior locations in the Big House between 24 and 29 April 2010 (spring).

RH readings were collected in both entrance vestibules. “The moisture from the melting snow will help to humidify the air in the vestibule, and also the building itself” (Freitag and McFadden 1997). Not unexpectedly, the RH readings were much higher in both vestibule locations, with averages of 73 and 76% for the west and east vestibules, respectively (Fig. 10). The minimum RH reading of 31% occurred in the east vestibule, with maximum values reaching saturation at 100% for both. The dataloggers measure RH only to 100%, and, consequently, result in the flat peak of the curve in the figure. The RH in the west vestibule shows more of a diurnal trend as the RH increases during the day and decreases at night. While the east vestibule RH readings spiked with the high humidity, the minimum values remained close to 70%. Visually, there was frost buildup on the windows of the exterior entrance doors, but not on the interior

entrance doors (this indicates that the vestibule is acting as it is designed to act).

Calculated partial vapor pressure

Outdoor and indoor partial vapor pressure was calculated using the temperature and RH data. The partial vapor pressure describes the properties of the moist air mass and was calculated using the formulations in ASHRAE (2009). Figure 11 shows the calculated outdoor and indoor partial vapor pressure values from 25 April to 1 May 2010. The graph shows that both the indoor and outdoor partial vapor pressures vary, as expected. The outdoor partial vapor pressure is much lower compared to the indoor. In general, the direction of the primary moisture drive occurs from inside to the outside of the building. Figure 12 shows the partial vapor pressure during the time period from 26 May to 1 June 2010. The range of outdoor partial vapor pressure increased compared to that in Figure 11.

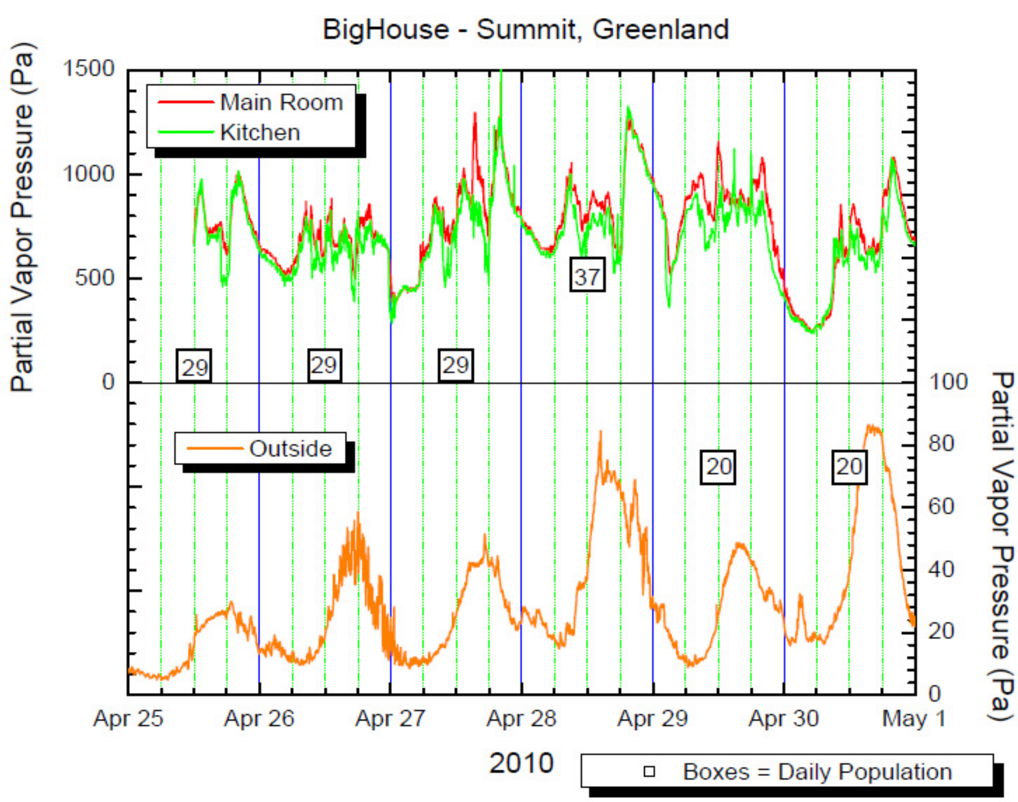


Figure 11. Outdoor and indoor calculated partial vapor pressure from 25 April to 1 May 2010.

Indoors (main room and kitchen), the trends track each other closely (Fig. 11 and 12). The exception is when one of the rooms becomes either a “source,” such as when moisture is being added or a “sink,” when moisture is removed, such as when the stove vents are operating, pulling moisture out of the building. Similar trends are shown during the 6-day period from 26 May to 1 June (Fig. 12). Both Figures 11 and 12 include the station population. However, the variability in the partial vapor pressure appears to be affected more directly by the type of activity (cooking or showering), rather than the number of people, bearing in mind that the number of people present increases the potential for more cooking, more showers, etc.

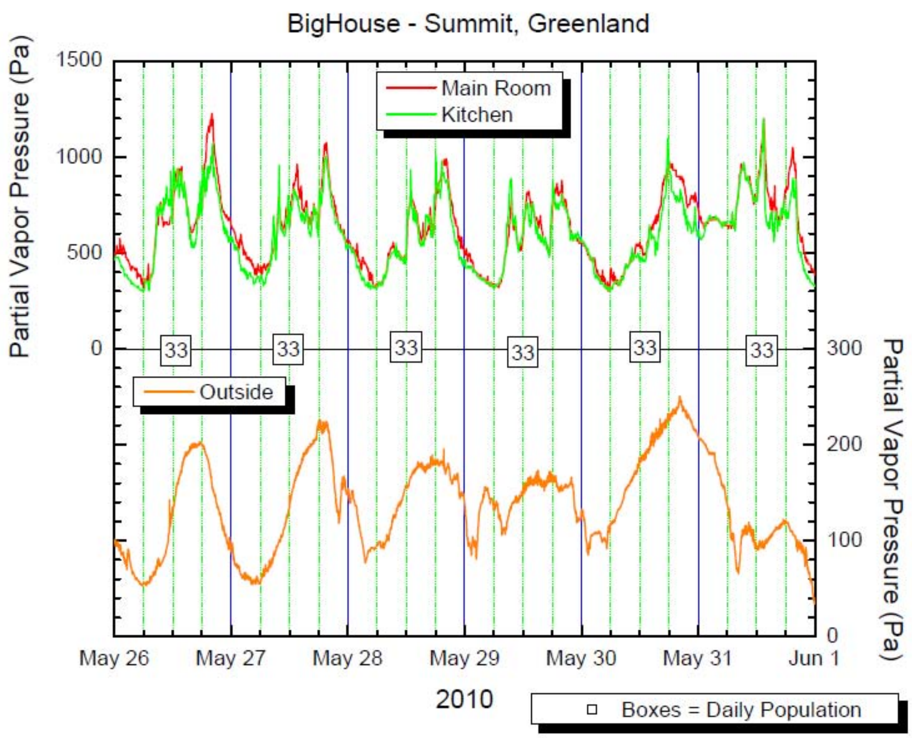


Figure 12. Outdoor and indoor calculated partial vapor pressure (26 May to 1 June 2010).

Infrared survey

The IR survey was conducted by initially collecting exterior images from designated points around the structure. The survey was done after the sun had set to reduce the effect of solar loading. The digital photos were taken at the same points, but during the daylight, to show as much detail as possible. The interior IR survey and digital photos were taken late at night when there was less activity in the Big House so as not to interfere with the normal workday activities.

From the original 25 exterior positions circling the Big House, 14 were chosen, as they provided adequate coverage of the entire facility (Fig. 13). All 14 views are shown on the website. Eleven of those the views, plus the roof and base, were selected for discussion in this section of the report.

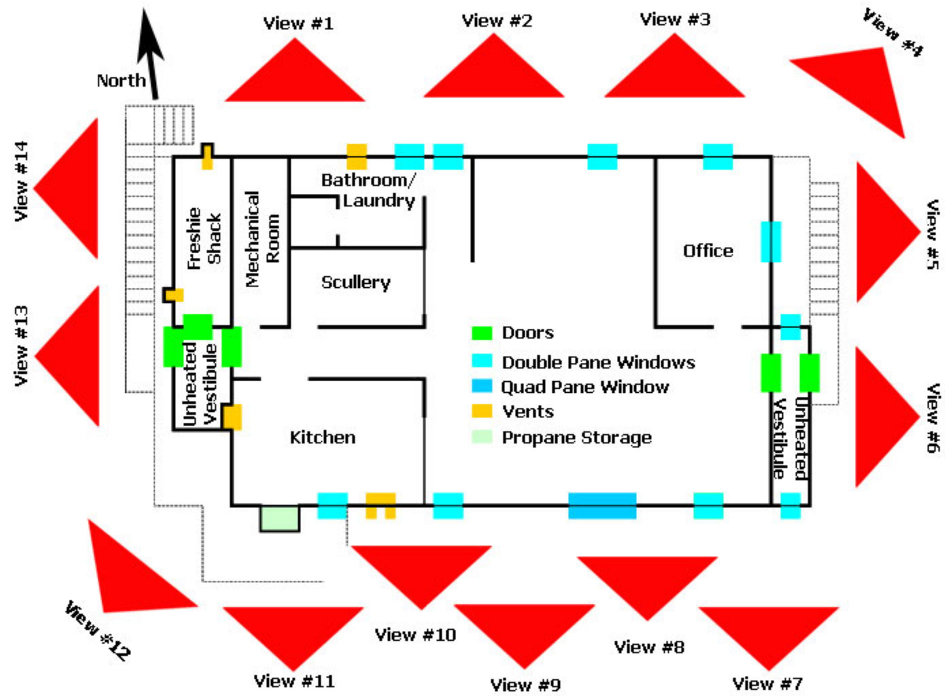


Figure 13. Exterior views of Big House.

Exterior building images

Beginning on the north side western end of the Big House, **View 1** (Fig. 14) includes the exterior wall of the mechanical room, freshie shack, and access stairway of the west entrance. The west vestibule (with dimensions of 2 m wide × 6.8 m long) was added to the main structure in 2006 (CPS and NSF 2009). There is a slight amount of frost buildup at the bottom of the fresh air vent to the freshie shack. The bright spot on the roof is the heated vent pipe for the sewer in the mechanical room. The transition between the original construction and the freshie shack shows some heat loss at the common wall between them. The bright area along both the sides and bottom of the fresh air vent indicates heat loss out of the freshie shack, although the vent on the inside was covered with cardboard. The freshie shack consists of a 100-mm SIP, covered with an interior metal skin commonly used for food storage. The exterior of the west vestibule is 12.5-mm T-111 siding and, on the north side of the building, is aligned flush with the existing T-111 siding.

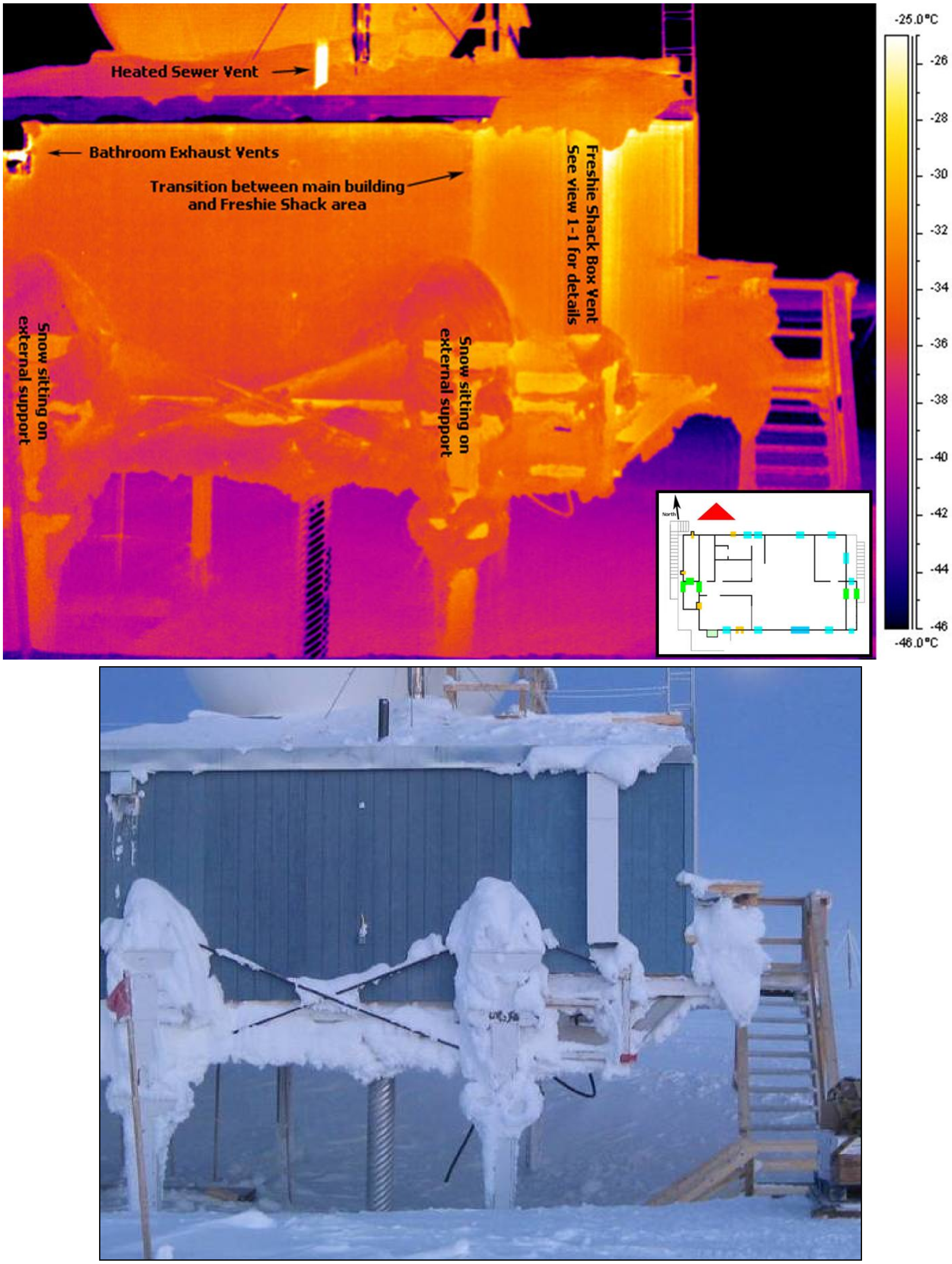


Figure 14. View 1 showing location (inset), thermal, and visual image of the exterior North side West end.

The set of images in Figure 15 are from **View 2** in the mid-section of the north exterior wall. The main room window is on the far left and the windows to the right are those in the hallway and laundry room/bathroom.

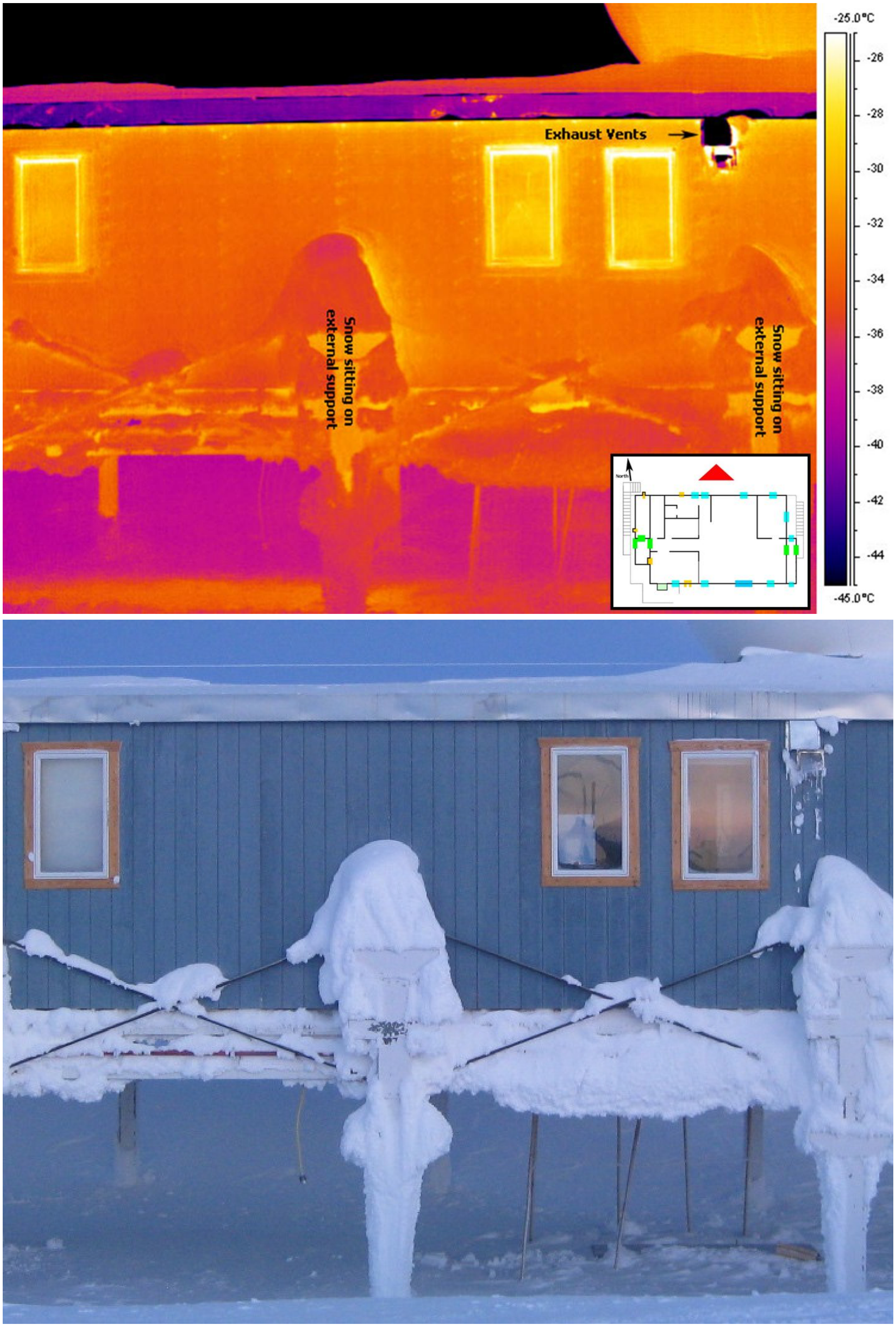


Figure 15. View 2 showing location (inset), thermal, and visual image of the mid-North exterior wall in the vicinity of the laundry room and main room.

The existing windows were installed during the original construction and are operational, double-pane casement windows having 58- × 1092-mm exposed glass and wood frames. In the IR image, the window header (top of the window) is a warm spot, indicating heat loss from the building. Heat loss is possible from the wooden window frame and the window opening in the wall system, as this tends not to be as efficient as the surrounding wall system. There may also be a gap between the window frame and the wall that requires additional insulation.

Current plans call for triple pane windows to replace the existing double-pane windows. At the time of installation, the condition of the opening should be assessed and additional insulation should be added. The triple-pane windows should also reduce heat loss through the glass in the window. An example of the improved efficiency beyond a double-pane window is discussed with the fixed quad-pane window on the southern side of the building (View 8, Fig. 20).

Also in **View 2** are the two vent penetrations in the laundry room/bathroom area. The clothes dryer vent is above the wall vent. In the IR image, they are seen as the darkened shapes because of the reflection of the clear sky on the metal. The upper dryer vent was functional, as indicated by the frost buildup on the exterior wall. At the time of the field visit, the heat and moisture from the dryer was vented into the laundry room, yet some heat and moisture still flowed out through the wall vent. Warm, moist air blowing up toward the eave also contributes to the ice buildup. The lower vent was a direct vent, and while it was not operational, it is a penetration that allows cold air to enter the building.

The images at the eastern end of the north wall, as shown in **View 3** (Fig. 16), include the office window (left) and the main room window (right). Both windows are wood frame, double-pane casement. The fuel tank on the deck is the round, snow-covered object located on the far left in the image. Consistent with the windows in **View 2**, the headers at the top of both windows have a brighter area in the IR image, indicating heat loss, and there is more heat loss through the window pane compared to the wall. Heat loss at the top of a window is common as this is a discontinuity within the wall system, and there may be a gap between the wall and the window frame.

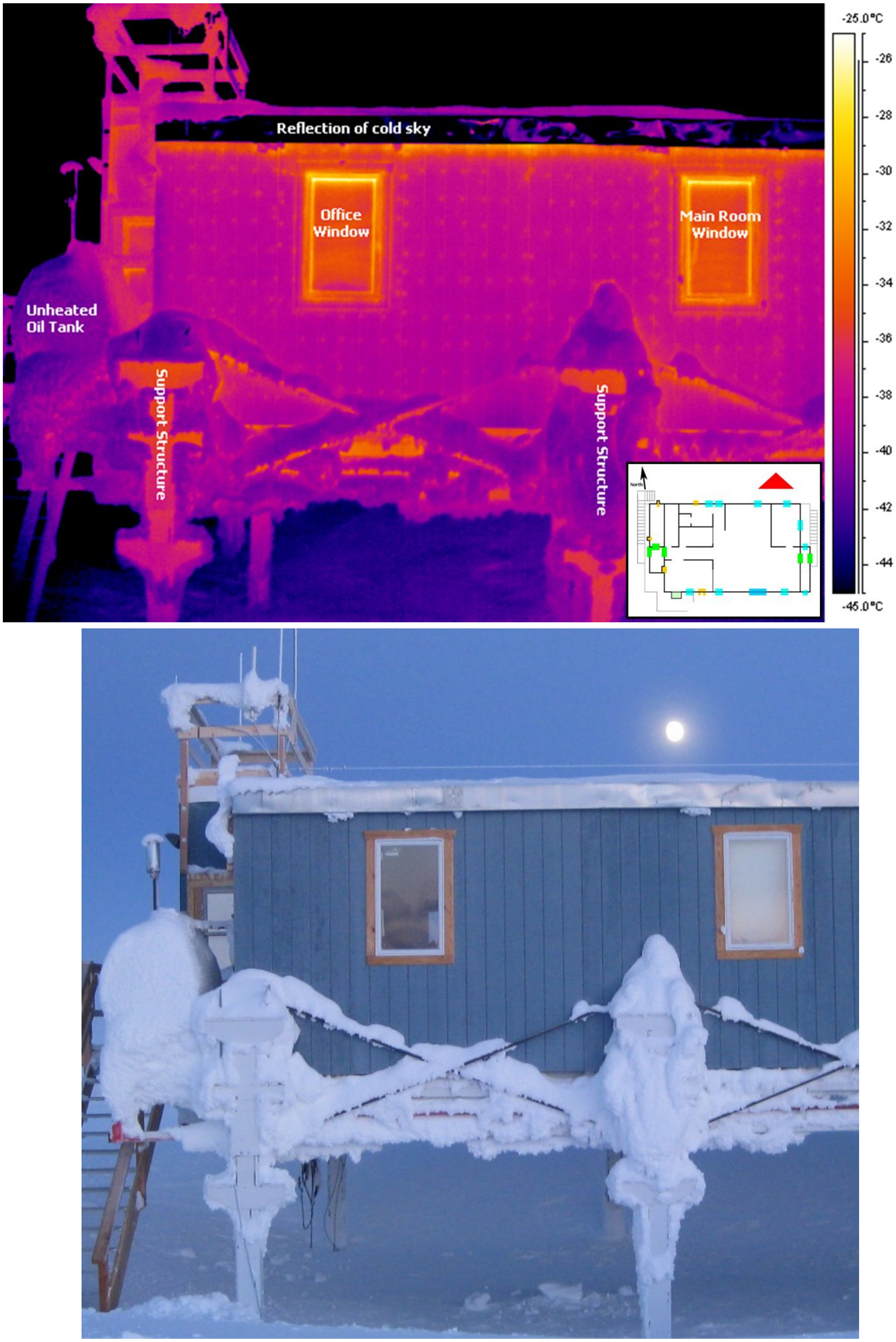


Figure 16. View 3 showing location (inset), thermal, and visual image of the eastern end of the North exterior wall in the vicinity of the office and main room.

While windows and doors are essential to the function of a building, they create discontinuities in the building envelope and reduce the thermal resistance of the wall system. Reducing the heat loss through building envelope transitions, such as doors and windows, is improved with good frames and installation procedures.

The IR image also indicates heat loss at the eaves where the roof connects to the wall. This is often a location where it is difficult to achieve adequate insulation at the construction joints, resulting in a discontinuity in the thermal envelope. The visible dotted pattern along the face of the exterior wall, also seen in the previous IR images, is from the fasteners used when the exterior was re-sheathed with T-111 siding in 1999. The fasteners are seen throughout the exterior IR imagery.

Figure 17 shows **View 4**, the northeastern corner of the building, including the office and the unheated, entry vestibule. The heat loss through the header of the office double-pane window is consistent with the other windows. The double-hung window on the north wall of the vestibule maintained a layer of frost cover, as at the time of the field visit this window did not receive any solar heating. In cold climates, windows operate as dehumidifiers and provide a cold surface for moisture to collect. Heat from exposure to the sun warms the exterior surface of the glass window pane, and the frost melts. While the northern window remained frost-covered owing to the lack of sun exposure, the southern window cycled almost daily from frost-covered to frost-free and back from the amount of trapped moisture in the vestibule (from opening the entry door and the roof access hatch). Once melted, the potential for moisture damage is greater as the water either moves into void spaces or may freeze and thaw in place. If the windows are not really necessary, it would be best to remove them from the vestibule to reduce moisture buildup. Another method to reduce the amount of moisture buildup in arctic entryways is to maintain a constant cool environment (between 2 and 5°C) to mitigate the large temperature swings in an unheated vestibule.

The bright spot in the upper center of the image (above the vestibule window) shows both increased heat loss and air exfiltration around a cable pass-through that appears not to have been insulated and resealed. On the interior of this wall is a computer server cabinet that generates a considerable amount of heat. The brighter

horizontal line above the doorway in the vestibule shows heat loss through the seam where the ends of the T-111 sheathing butt together. This is also clearly visible in the next IR image.

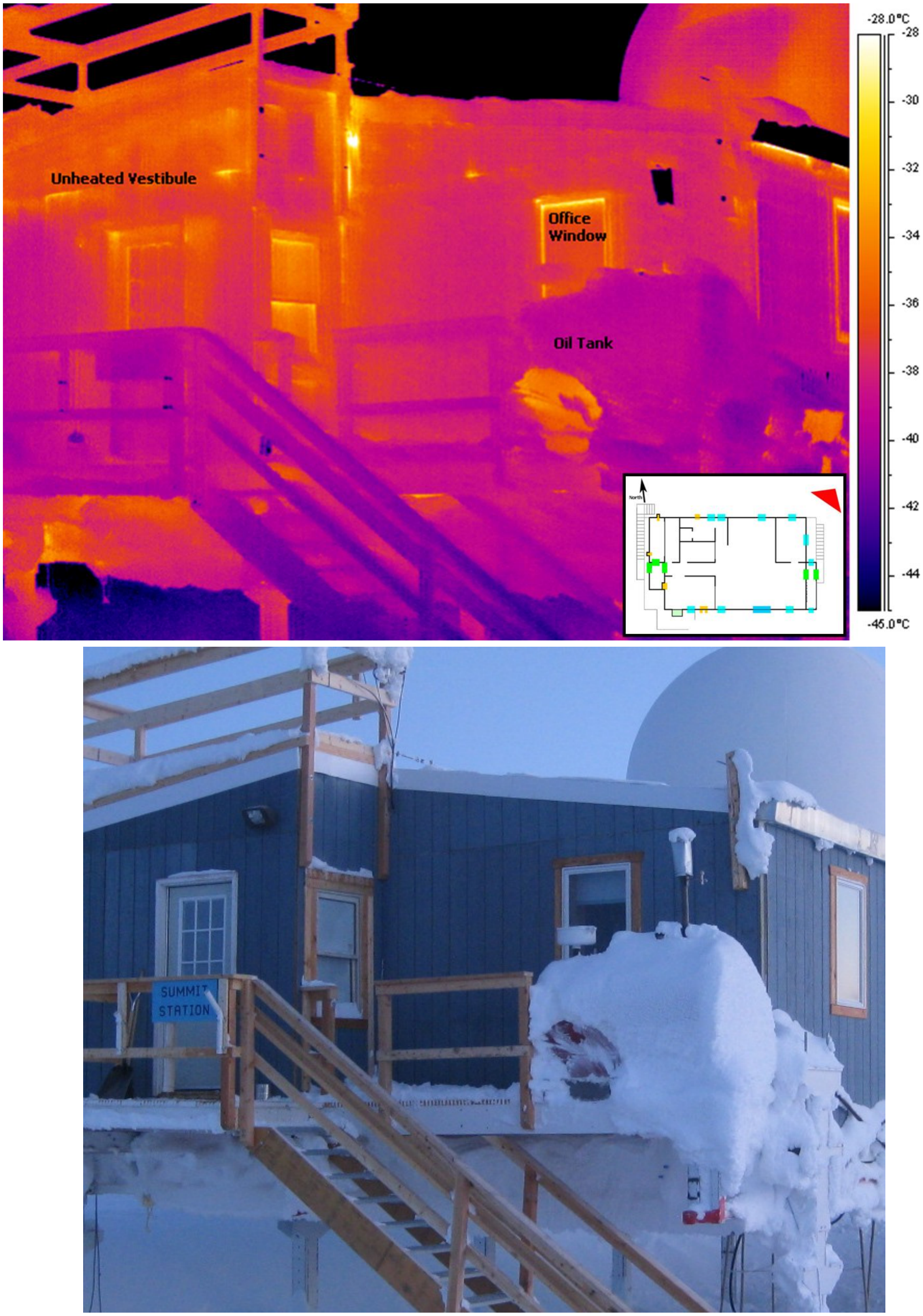


Figure 17. View 4 showing location (inset), thermal, and visual image of the northeastern corner including the office and eastern unheated vestibule.

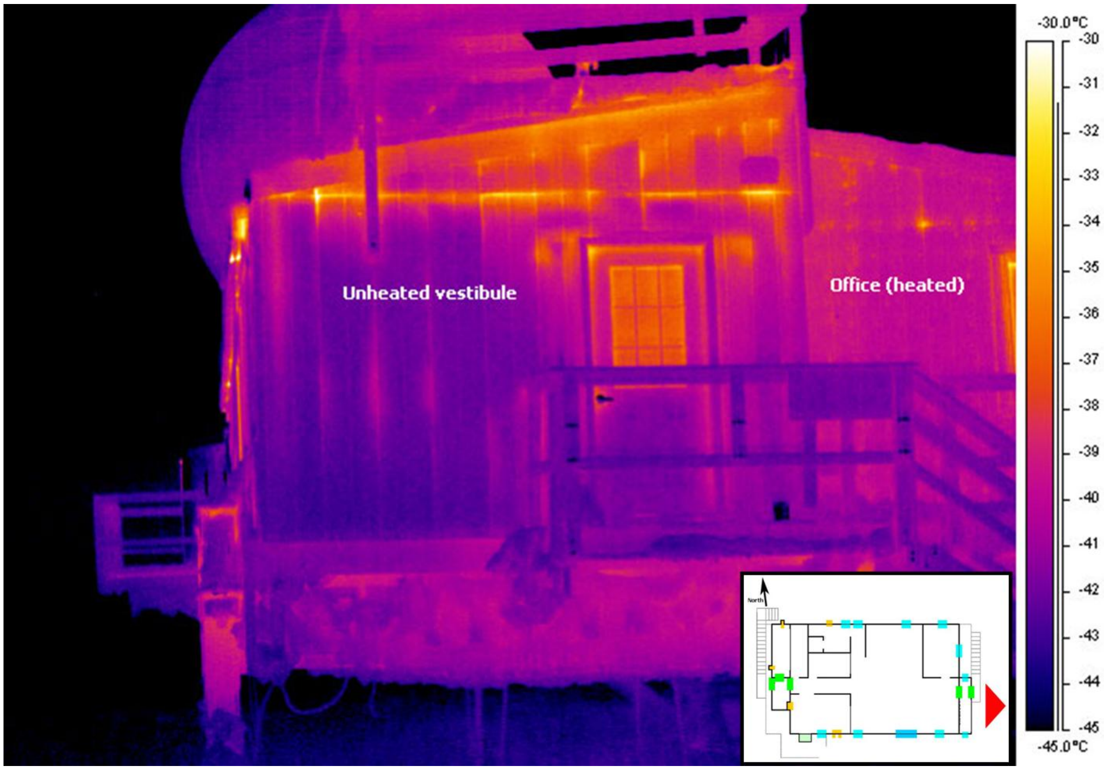


Figure 18. View 6 showing location (inset), thermal, and visual image of the eastern end of the Big House.

View 6, shown in Figure 18, is the southern portion of the eastern end of the Big House, and highlights the unheated entry vestibule. Again, the bright horizontal line at the interface of the T-111 siding indicates heat loss from the upper ceiling of the vestibule. The ceiling in the vestibule is open and slanted. The access hatch to the roof is located in the ceiling of the vestibule. During the visit, there was a substantial amount of frost built up on the access hatch on the inside of the vestibule.

Moving to the southern side of the building, **View 7** (Fig. 19) shows the eastern end of the southern side. The two windows in the IR image are a wooden frame double-pane casement window in the main room (left) and a wooden frame double-pane double hung window in the vestibule (right).

The IR image illustrates the difference between the thermal envelopes from the main room of the heated building, and the unheated vestibule, and the different types of wall systems (SIPs of the main building and the standard framing of the vestibule). There is heat loss through the transition, identified in the IR image in Figure 19, between the main room and the vestibule. The southern window in the vestibule regularly receives sunlight exposure, which minimizes the amount of frost buildup compared to the double-hung window on the north side of the vestibule, which receives no solar gain.

Along the eave are two bright spots showing heat loss from penetrations where previous instrumentation was mounted to the exterior (to the right of the main room window) and existing cables' pass-through to the roof (at the common wall between the main room and vestibule). The area on the right was sealed from the interior prior to the ERDC-CRREL field visit. Re-insulating the empty cavity through the wall should be considered to completely seal the opening and reduce heat loss. Designated cable conduits through the building envelope should be considered to decrease the number of penetrations for cables. This also ensures that the opening can be properly insulated.

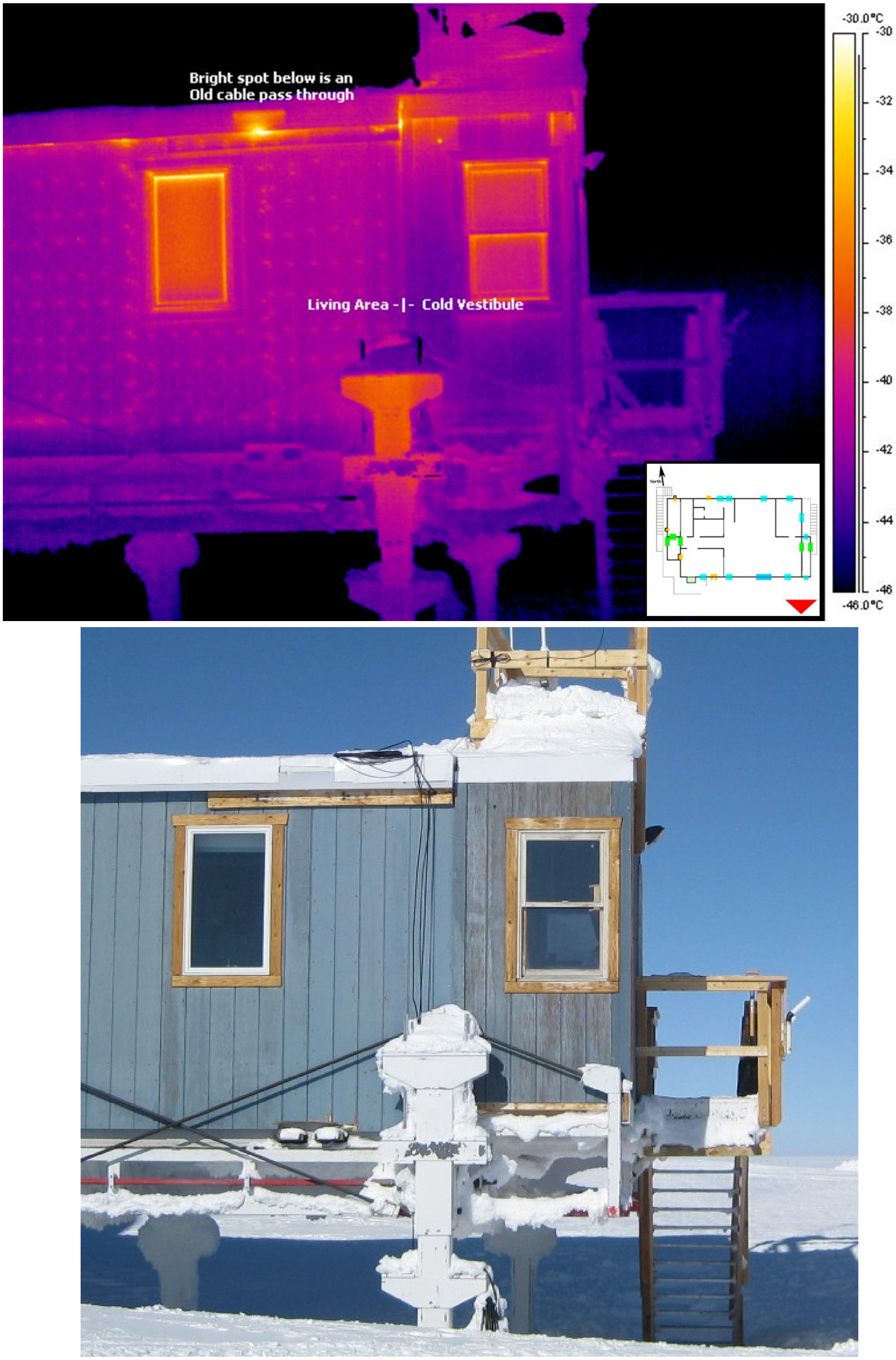


Figure 19. View 7 showing location (inset), thermal, and visual image of the eastern end of the South exterior wall in the vicinity of the main room and east vestibule.

View 8, shown in Figure 20, is a good example of the difference in heat loss between double-pane and quad-pane windows. The IR image shows less heat loss from the quad-pane window, as the temperature along the glass is lower. There is a uniform brightness to the frame around the window, as the window opening is a discontinuity within the wall, and this shows the importance of installing and sealing the opening well. In the IR image, the bottom of the double-pane window appears to be warmer. This may be attributable to the electrical outlet below the window where computer charging units were plugged in.

The fasteners securing the sheathing are very visible in this image, each acting as a thermal bridge. There is also some heat loss along the wall–roof interface under the eave. In the image, the steel support column shows as warmer; the reason for this is unclear. Reviewing the IR imagery of other steel columns on the south, as well as on the north, side of the Big House reveals a similar trend. One possibility is the difference in the emissivity values between the columns and the T-111 (wood) exterior causing the columns to appear warmer. It is also possible that this slight difference in temperature is attributable to residual heat from daytime solar exposure. This is interesting and additional study may be needed.

The images in **View 10** (Fig. 21) include the kitchen stove vents and double-pane window (left) and the double-pane window in the main room dining area (right).

Both windows are the same type as the other casement windows previously mentioned and show similar characteristics in the IR image, with heat loss at the window header. The window on the right in the main room shows additional heat loss, and has about a 5°C temperature difference at the four bright spots under the window. This heat loss may be associated with the installation of the window, possibly ascribable to the counter on the interior that blocks the very bottom portion, or degradation of the window over time from moisture.

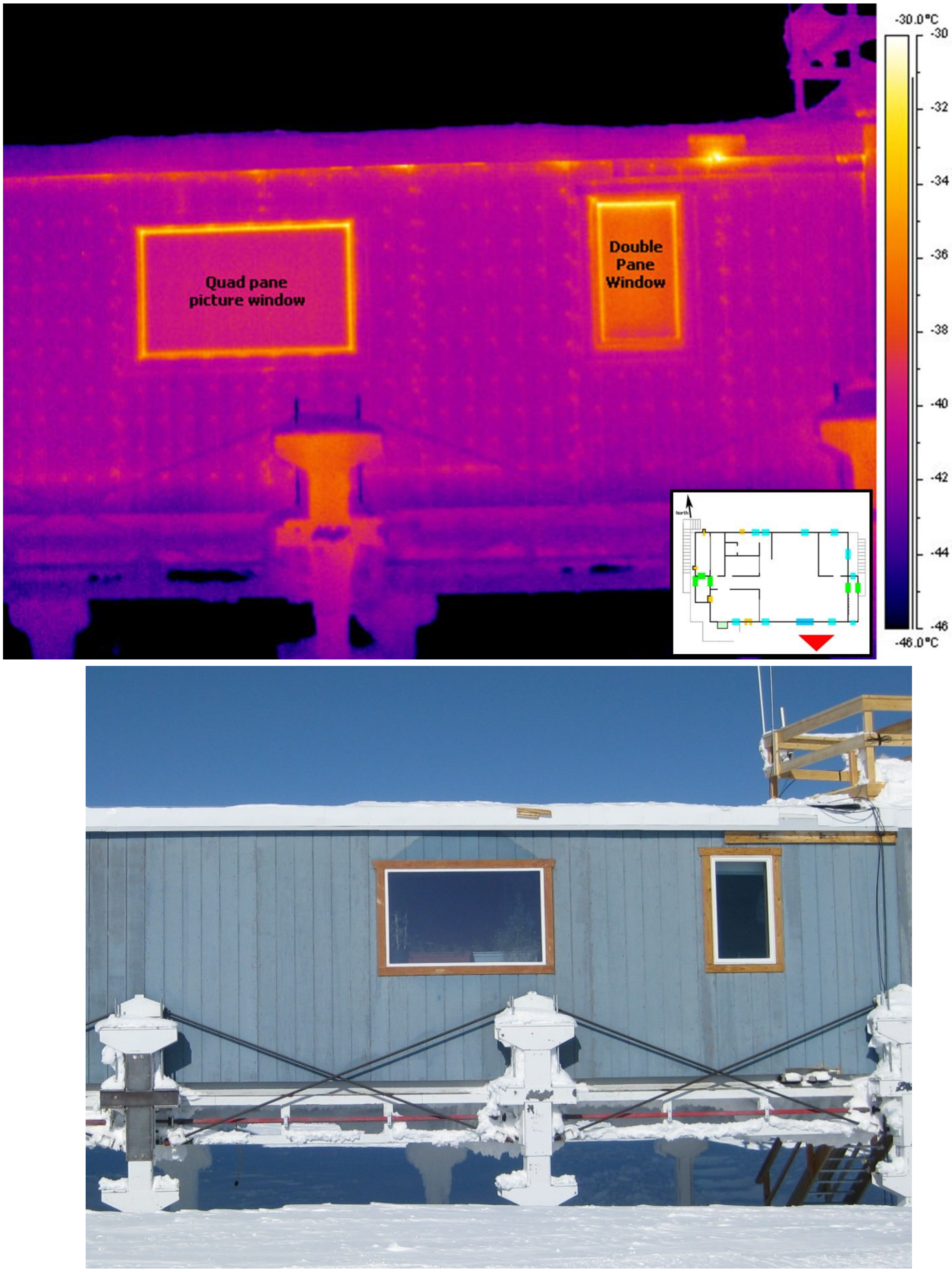


Figure 20. View 8 showing location (inset), thermal, and visual image of the South exterior wall in the vicinity of the main room.

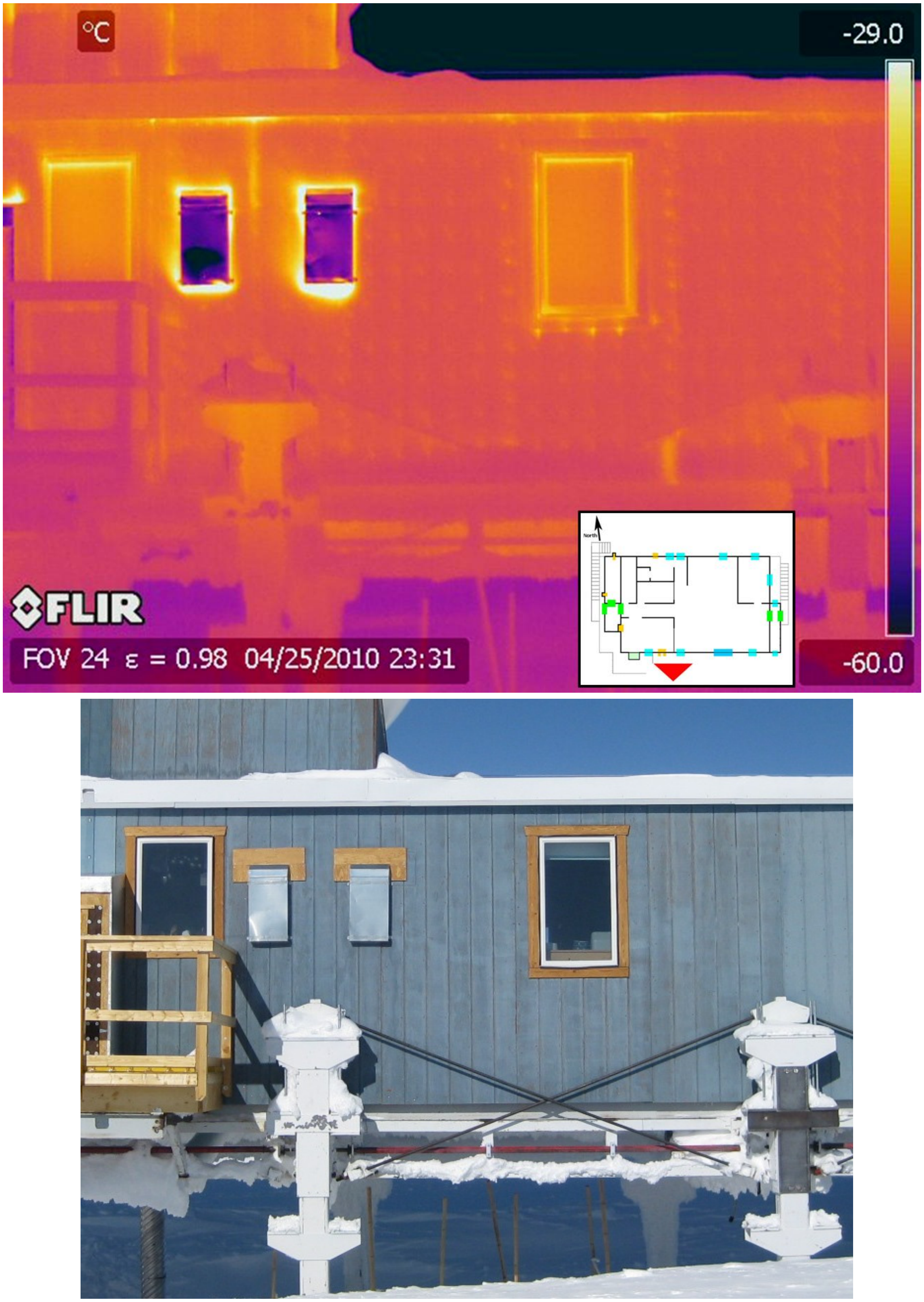


Figure 21. View 10 showing location (inset), thermal, and visual image of the south exterior wall in the vicinity of the kitchen.

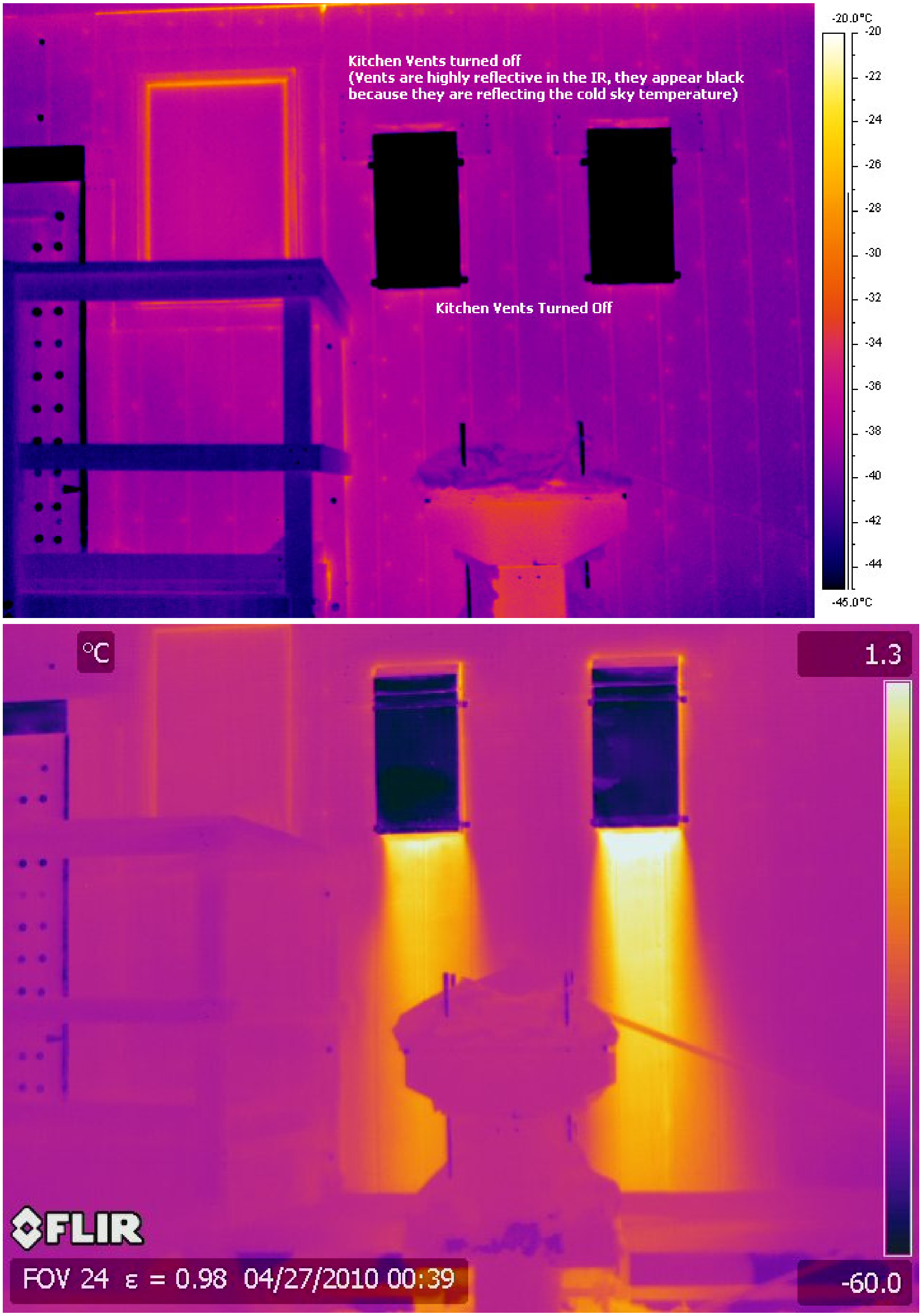


Figure 22. Thermal image taken before and during stove vent operation.

The stove vents (Fig. 22) display very darkly in the IR image because the metal reflects the cold sky. At the time this IR image was taken, the stove vents were not operating.

In contrast, the stove vents were operating (but there was no cooking) in Figure 22 to show the movement of interior air through the vents. On the interior, when the vents are not operating, they are a pathway for cold air to enter into the building, resulting in cold air infiltration.

Also shown in this set of images is heat loss through the wall system between the stove vents and loss at the wall–roof interface at the eave. On the inside, there is a support bolt in the kitchen ceiling that connects to the base of the radome that may have caused a flaw, or this may be near a roof beam location.

View 11 (Fig. 23) shows the western end of the south side exterior wall, including the radome on the roof. The top portion of the radome base is warmer than the bottom, and there is another warm spot at the roof eave. There is a small heat trace system installed in the radome to keep the instruments warm. The box structure that supports the radome may retain some of this heat. The top of the radome is cold, suggesting that there is not an excessive amount of heat loss. While there is a small heat leak at the base of the radome, it is not a significant amount. On the ceiling inside the Big House are bolts that attach through the roof SIPs that secure the base of the radome. These images indicate some, but not a significant amount of, heat transfer along the bolts. Also shown in this IR image is the propane storage area (center of image, double-door behind deck railing) that shows some heat loss from the heater that maintains a suitable propane temperature. Improving the gasket around the storage doors would reduce this.

The southwestern corner of the building is shown in **View 12** (Fig. 24) where the west unheated vestibule connects to the main building. The southern portion of the vestibule contains shelving for dry goods and also houses the 600- × 600-mm fresh air intake into the kitchen. The very bright spot at the interface between the main building and the vestibule is a gap indicating excessive heat loss. Further to the right, at the corner of the main building, the bright spot there is from a gap at the eave created when the building was re-sheathed (Fig. 25).

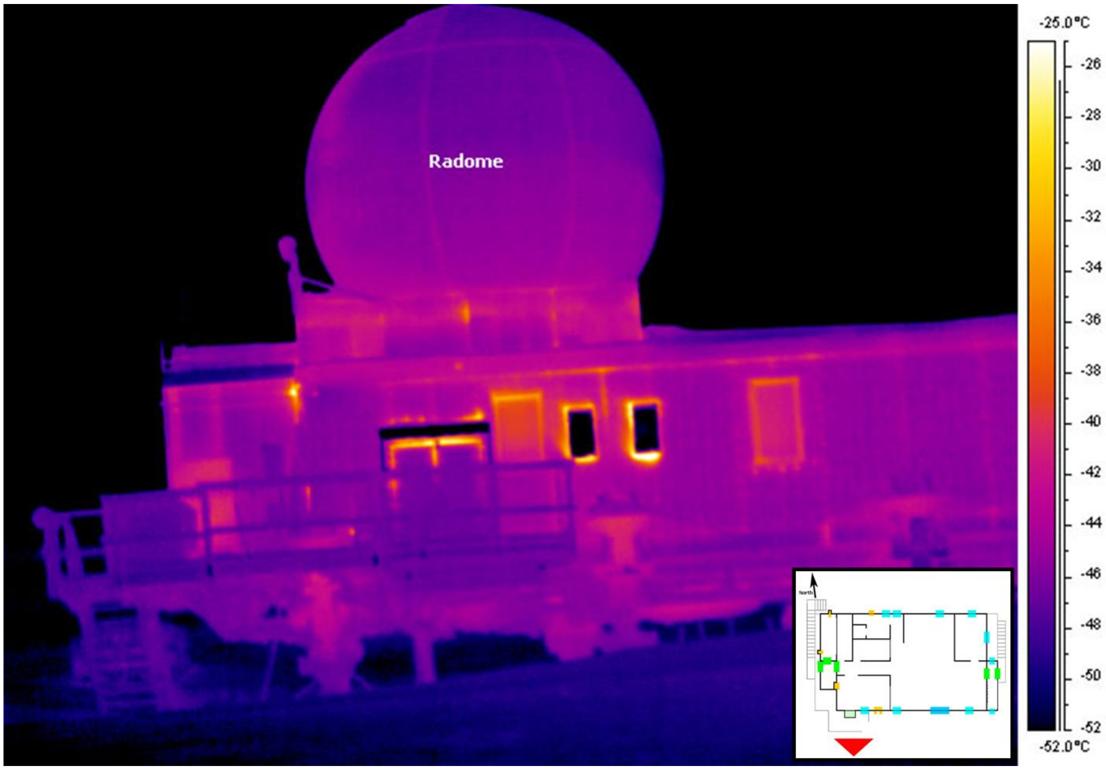


Figure 23. View 11 showing location (inset), thermal, and visual image of the of the south exterior wall west end in the vicinity of the kitchen.

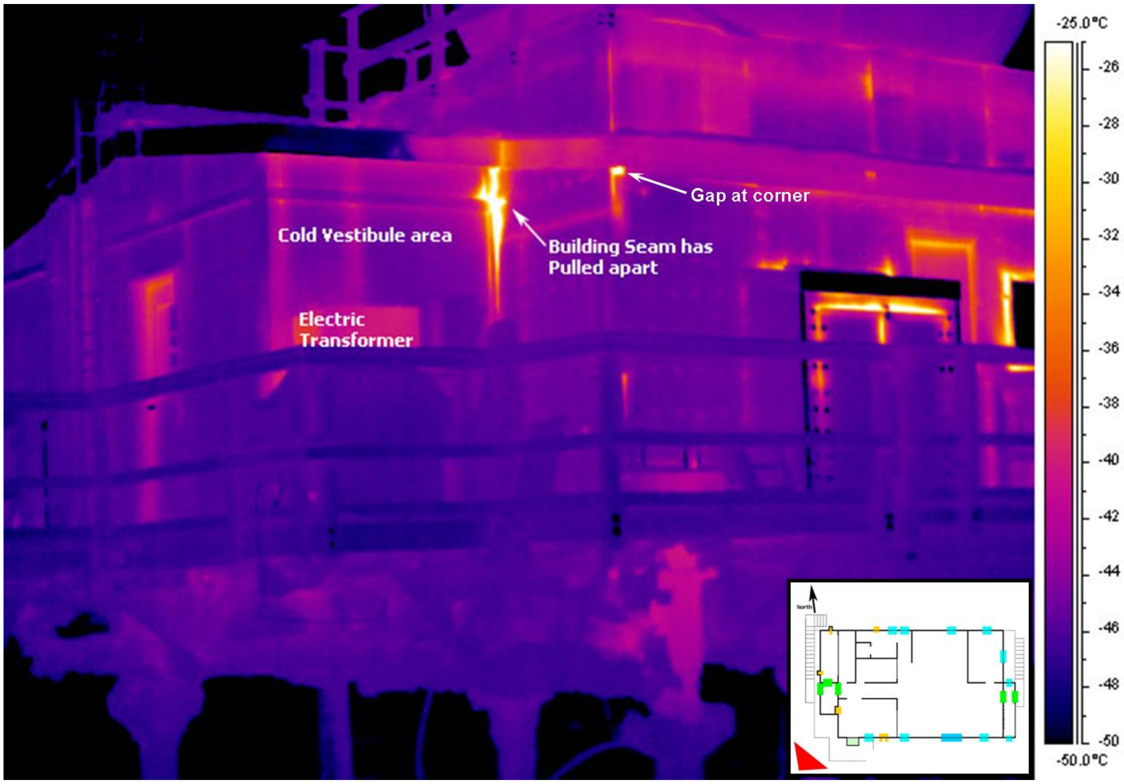


Figure 24. View 12 showing location (inset), thermal, and visual image of the of the southwest corner where the west vestibule connects to the main building

Figure 25. Closeup of the southwestern corner of the original main building showing the gap between the materials of the original exterior and the recent re-sheathing.

View 13, Figure 26 is a set of images showing the western end of the building. The vestibule is unheated and the freshie shack is located on the left side of the entrance. Heat loss is seen as the bright area along the top of the doorway. In the photograph, the white box (to the left of the doorway) is the vent for the summer intake fan into the freshie shack. It was covered with cardboard inside at the time of the IR survey. No significant heat loss is apparent.

Exterior roof images

Both IR and visual images looking at the western end of the roof were taken by CPS personnel (for safety reasons) from the eastern end of the building. The images shown for **View 15** in Figures 27 and 28 are the north and south sides, respectively. The bright pipe in the northern view (Fig. 27) is the heated sewer roof vent. The view of the southern side (Fig. 28) includes the base of the radome. Aside from the previously mentioned heat loss from the support base of the radome, there is no significant heat loss from the roof. The dark areas are the reflection of the cold sky on the metal roof.

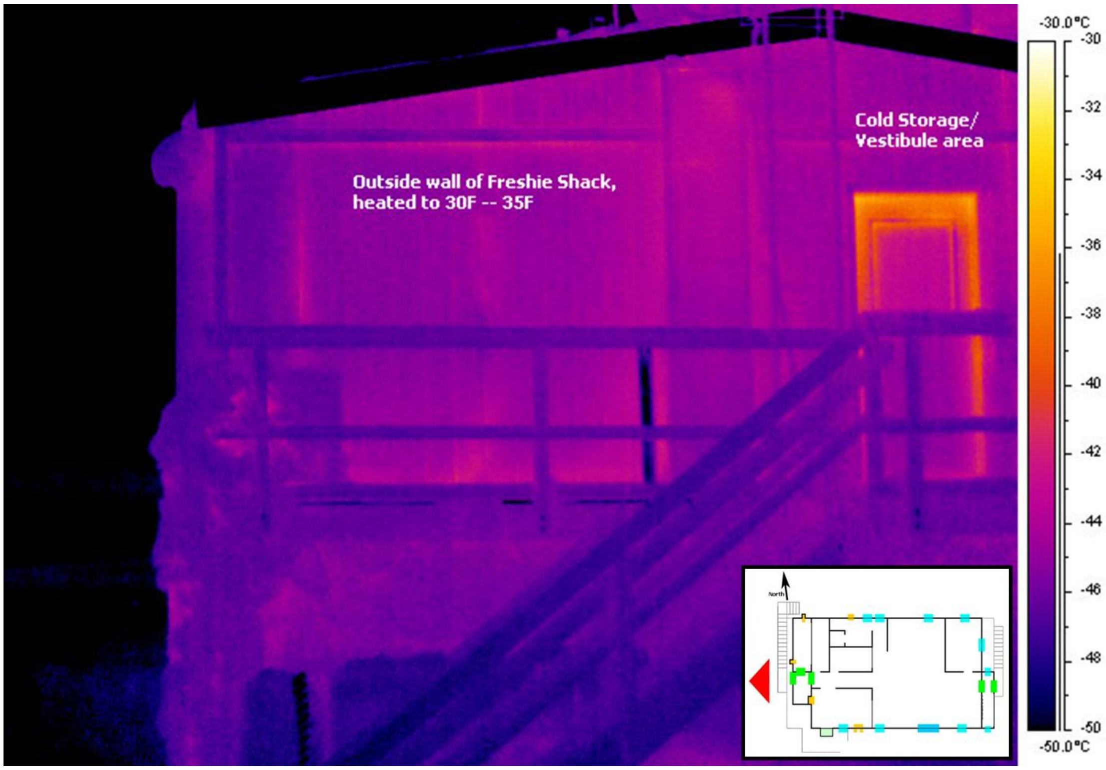


Figure 26. View 13 showing location (inset), thermal, and visual image of the of the west end. The freshie shack is on the left side of the entry door.

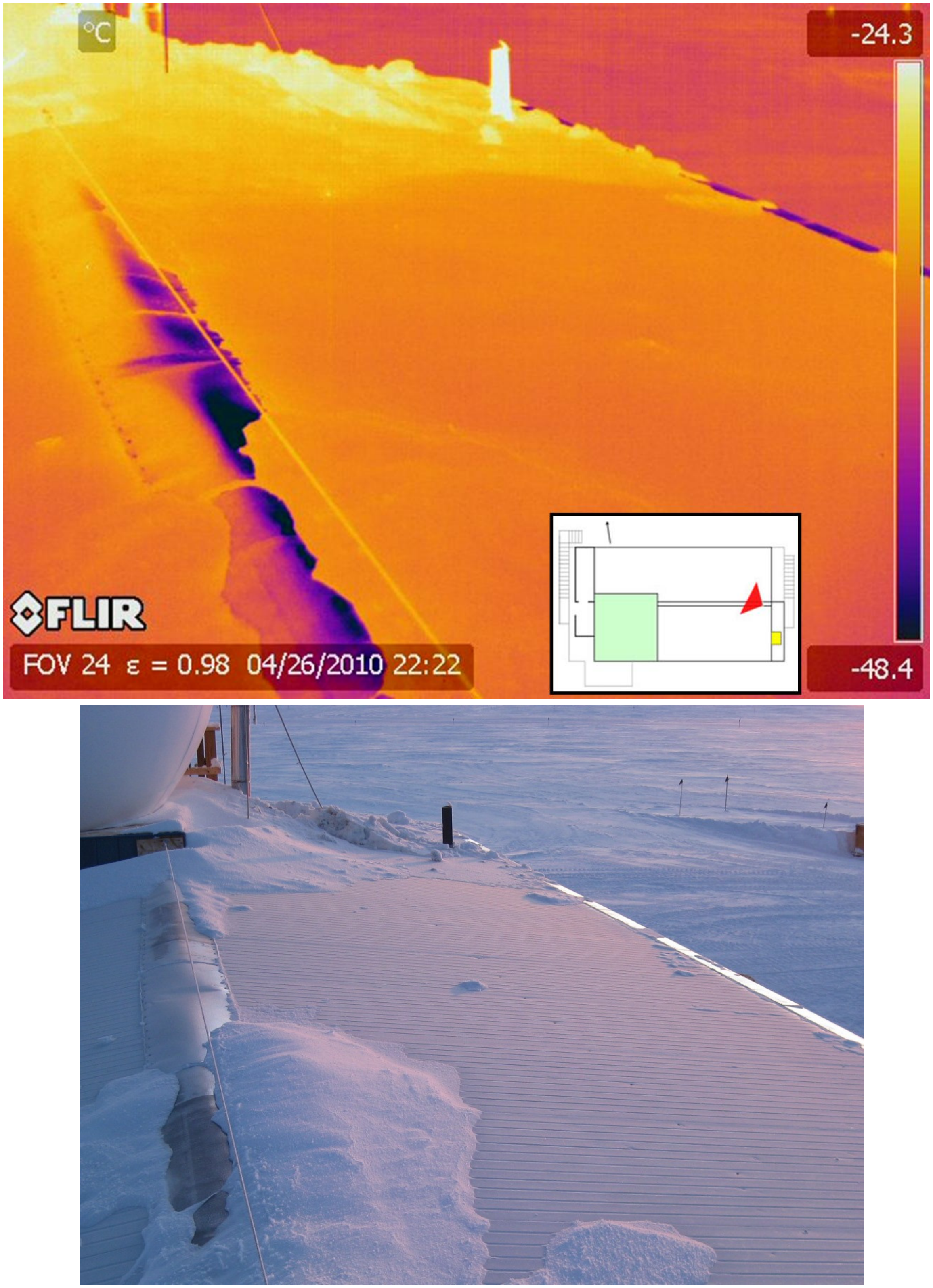


Figure 27. View 15 showing location (inset), thermal, and visual image of the northern side of the roof.

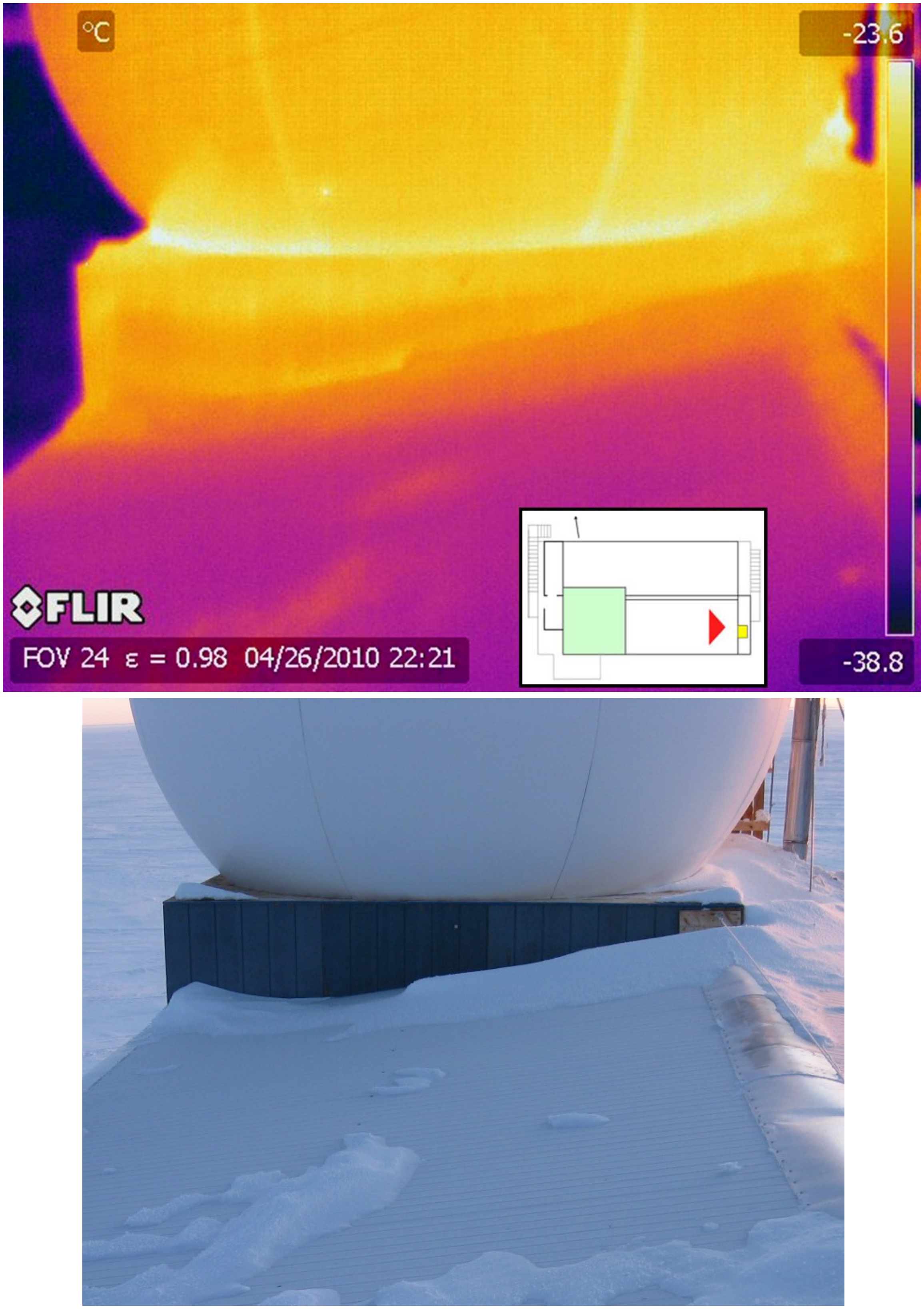


Figure 28. View of the southern side of the roof showing location (inset), thermal, and visual image taken from the same position (View 15).

Exterior base images

The base of the building was also imaged. The images in Figure 29 were taken of the base of the unheated eastern vestibule. These images were taken during daylight when the east vestibule warmed from solar loading. The bright areas indicate significant heat loss. Even though the vestibule is unheated, this figure illustrates the difference between SIP and standard timber construction methods.

Figure 30 shows the IR and visual images of the base taken on the northern side, approximately mid-way along the underside of the building. There is some heat loss, but not excessive, through the base of the building. There is also some unsecured sheathing that should be reattached.

Lastly, Figures 31 and 32 show IR and visual images of the sewer outfall pipe and the opening of the fresh air intake vent in the kitchen, respectively. The sewer outfall pipe shows some heat loss at the interface between the housing around the pipe and the base of the building. Likewise, there is heat loss from the kitchen through the air intake vent.

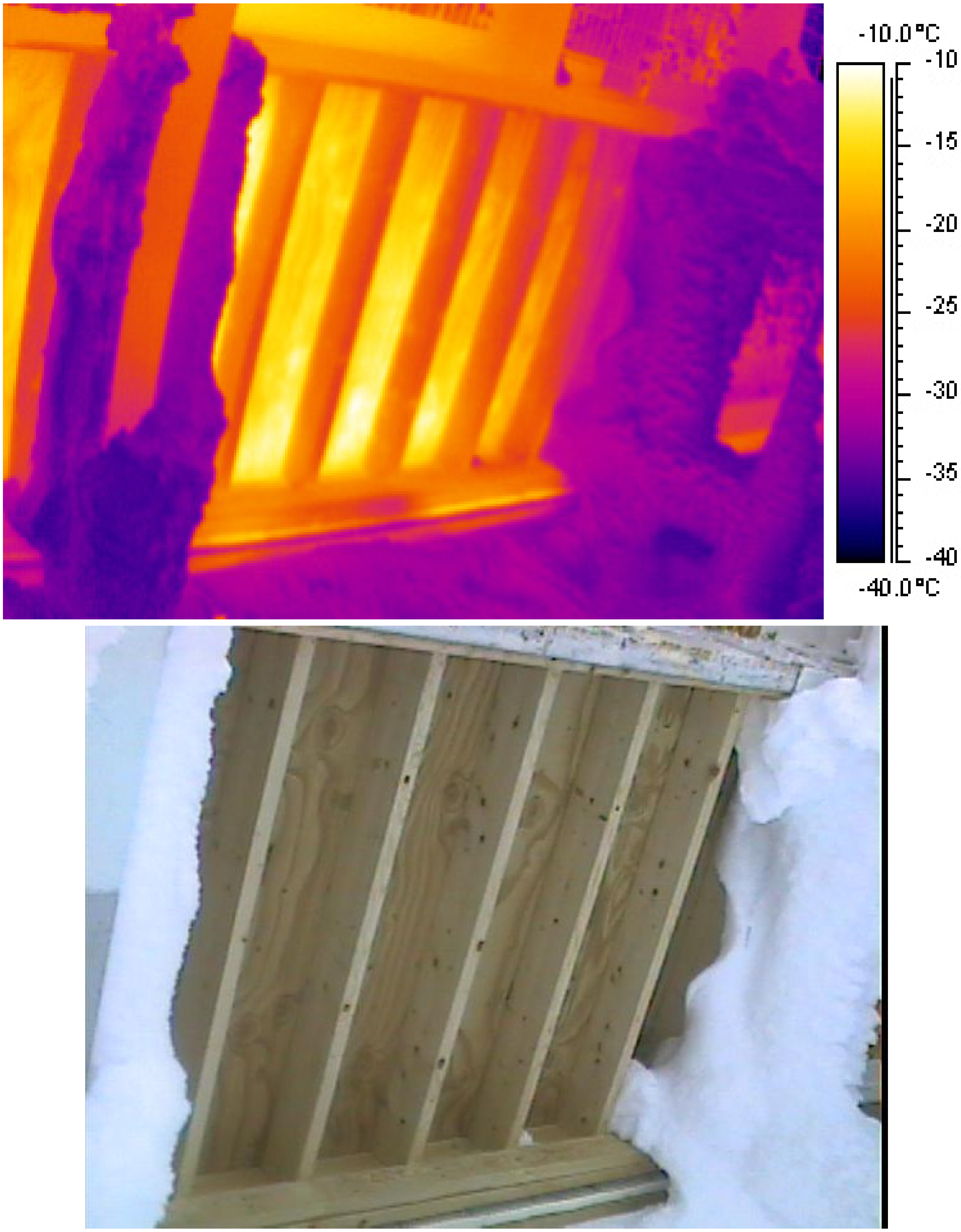


Figure 29. View showing thermal and visual image of heat loss through base of unheated eastern vestibule.

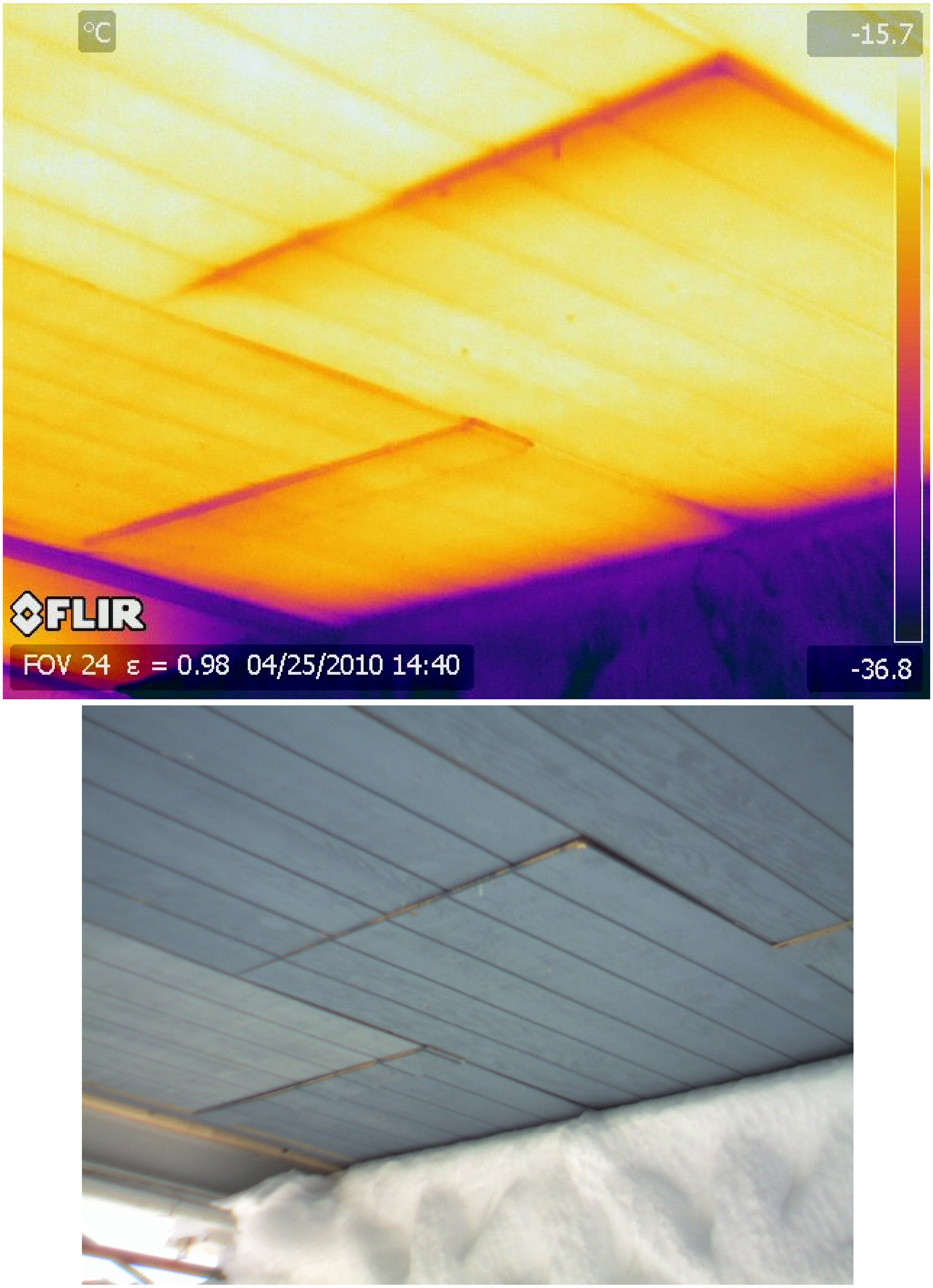


Figure 30. View showing thermal and visual image of unsecured sheathing on base of building.

Figure 31. Base of the building, IR and visual images of the sewer outfall pipe.

Figure 32. Base of the building, IR and visual images of the kitchen air intake vent.

Interior images

Selected locations from the kitchen, main room, office, and laundry room/bathroom are included in this section to emphasize observations in the IR imagery.

Kitchen

The large fresh air intake vent that brings outside air into the kitchen is a significant source of cold air infiltration (Fig. 33) and also supplies the building with make-up air for any combustion devices (such as the stove and furnace). The opening for the vent is on the underside of the building (Fig. 32). In contrast to the previous IR imagery, the dark colors here mean cold, as the vent fin is in contact with the cold air, and the warmer locations are reflected. The piece of blue tape on the top fin is reading –10°C. Also, in the west vestibule, there is frost buildup on the exterior of the vent under the shelves in the vestibule.

The vents located in the stove hoods are another location where cold exterior air infiltrates into the building, as shown in the IR image in Figure 34. Near this same place, on the wall behind the stove (Fig. 35), there is a cold location between two SIPs below the roof beam. This spot may be the same as the warm location seen on the exterior near the stove vents.

The bolts through the ceiling connecting to the base of the radome (Fig. 35) show locations of cold in the IR imagery. These are thermal bridges, and there are a number of these through the ceiling. They are condensation points for moisture in the air.

Also seen in Figure 35 is the sealant used around roof beams and along the roof-wall interface. This keeps the moisture from migrating through the wall.

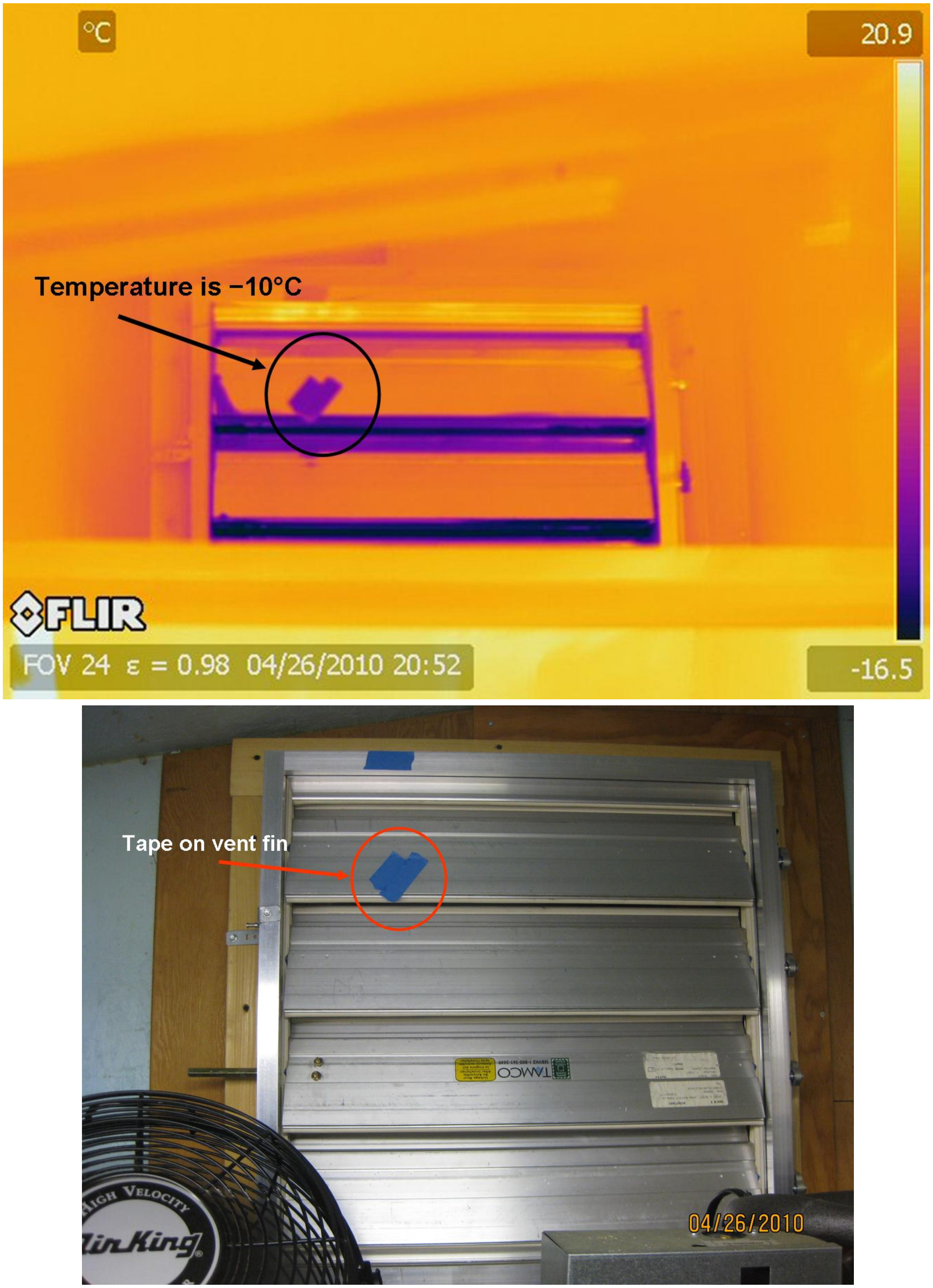
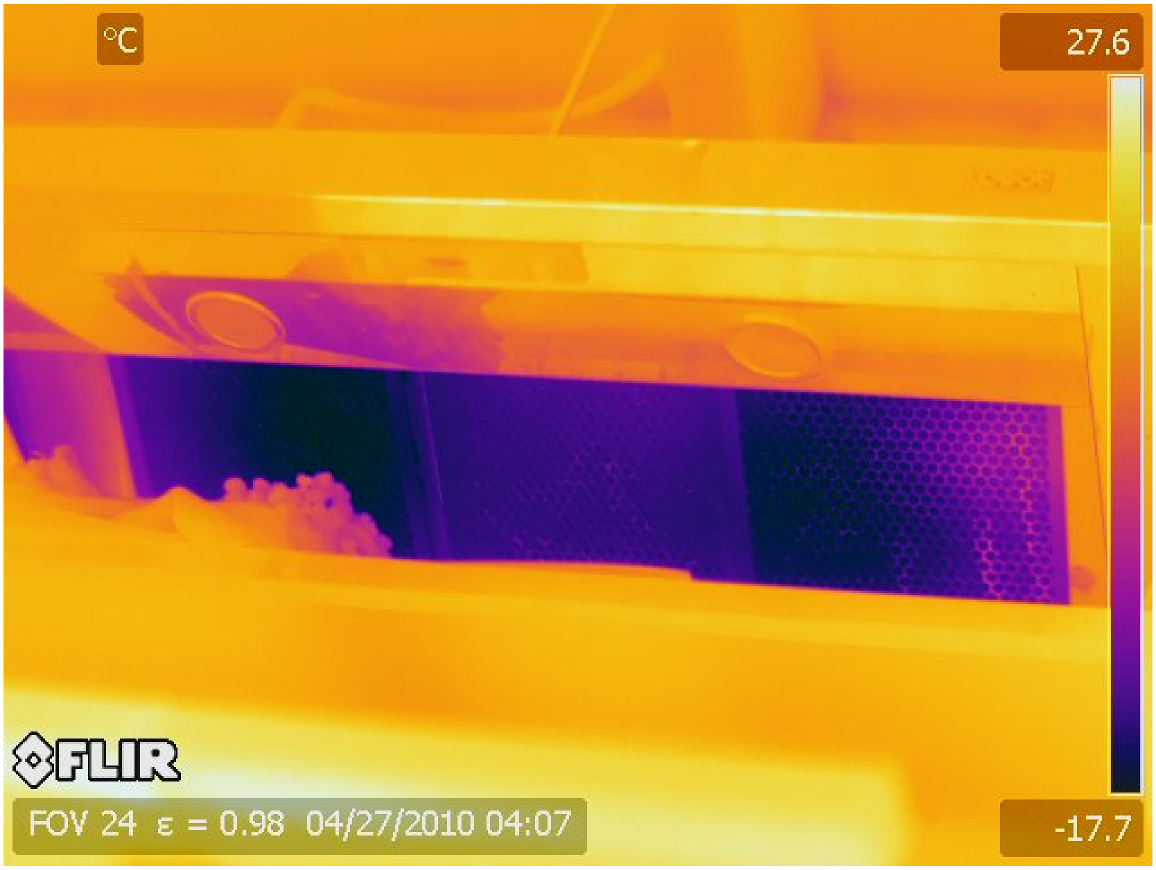


Figure 33. IR and visual imagery of the interior view of the large make up fresh air vent in the kitchen.



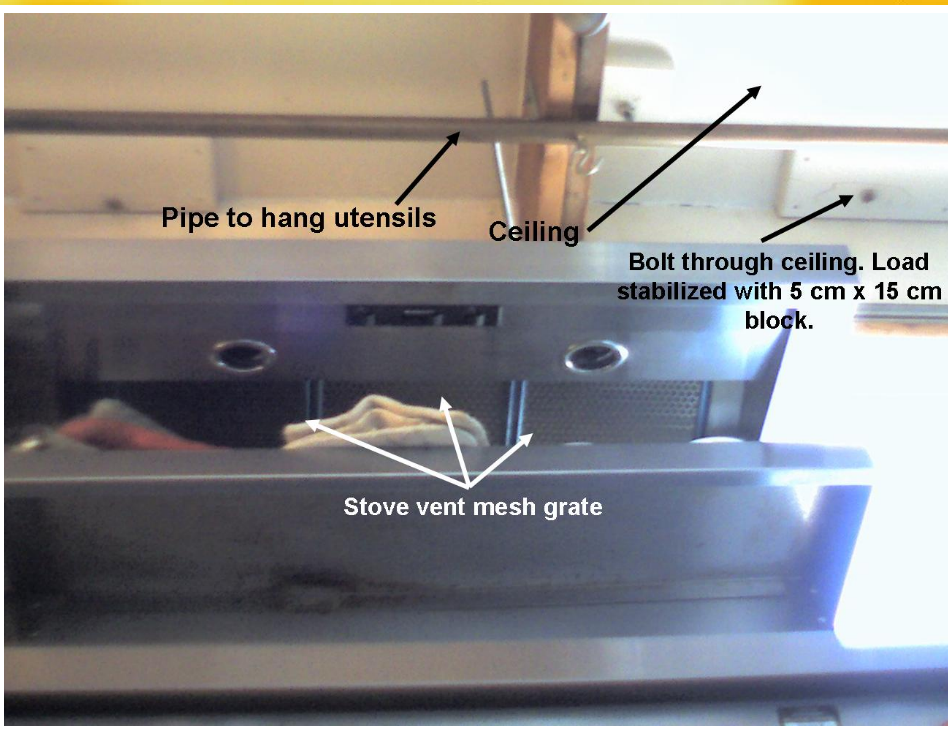
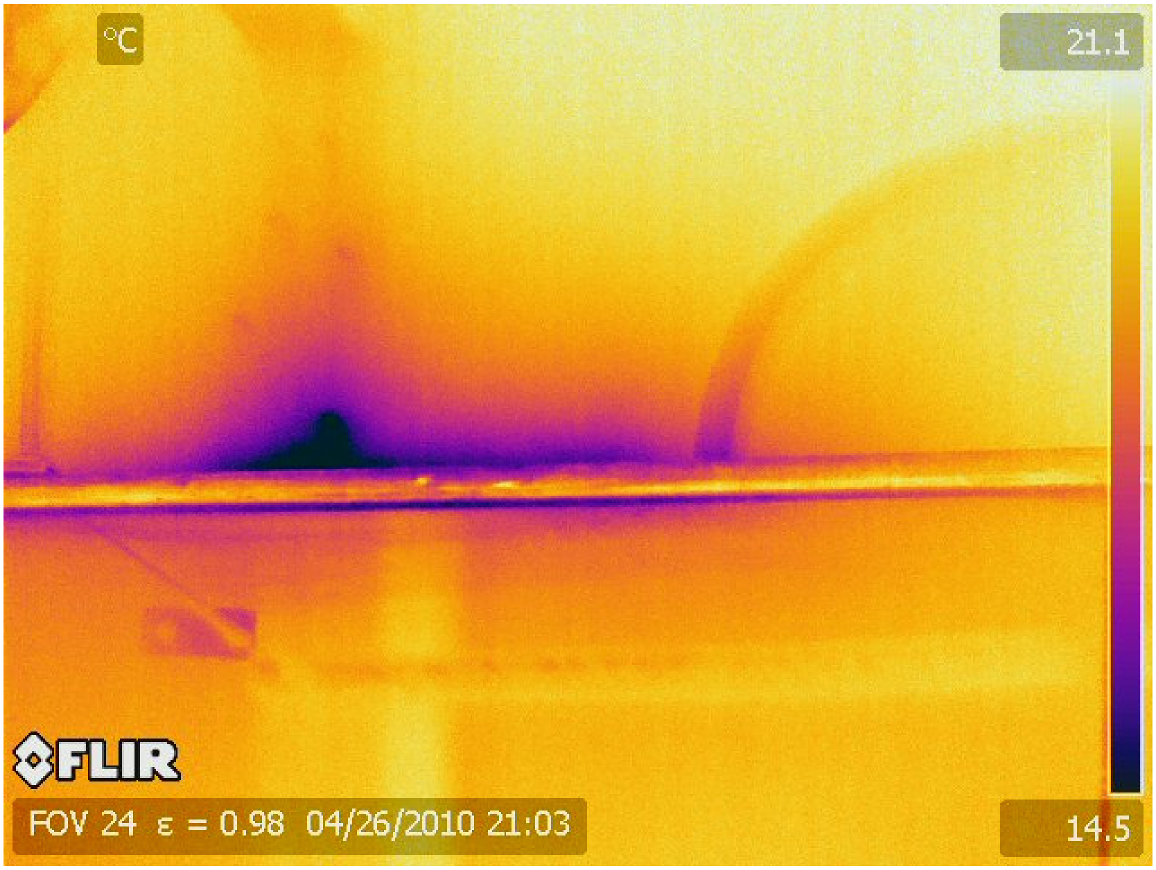


Figure 34. IR and visual imagery of the interior view of the stove vents in the kitchen.



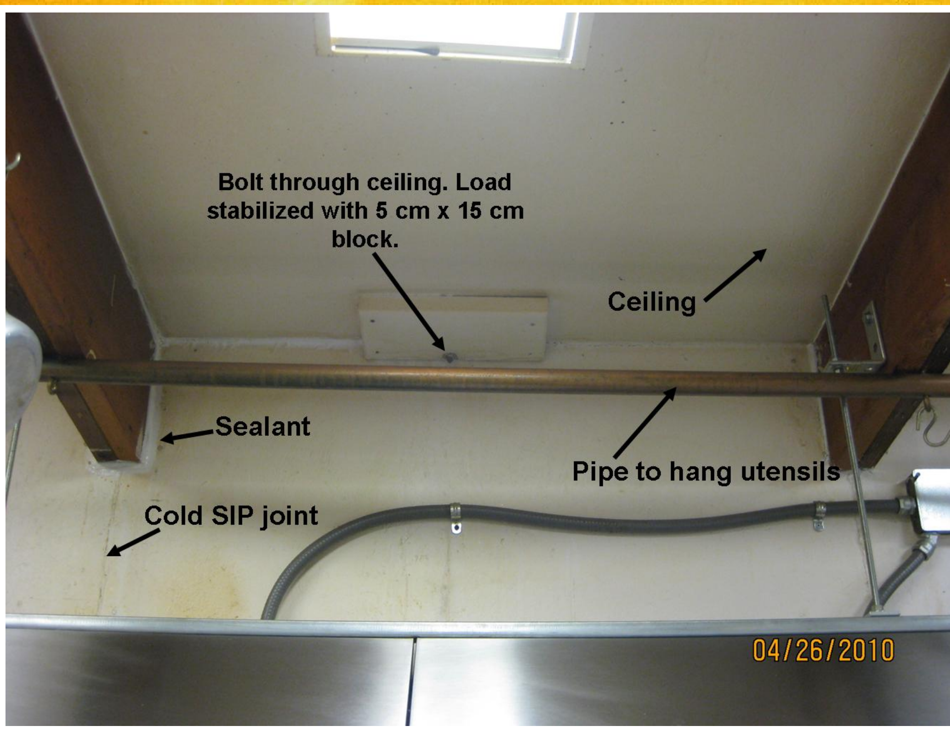


Figure 35. IR and visual images of the roof-wall interface behind the stove in the kitchen.

Main Room

A very cold location at the wall–floor interface was identified under the counter in the main room (Fig. 36). The lowest temperature was −5 to 10°C. It was sealed immediately and 15 minutes later, the IR imagery showed the temperature in the same area had increased by roughly 10°C. This is a great example of the benefits of sealing a leak. Air leaks, such as those at both the wall–floor and wall–roof interfaces, were found along the length of the building. Locations along the wall–floor interface are often blocked by furniture or are used as small storage areas, making them difficult to detect.

In Figure 37 the IR image of the quad-pane window shows a uniform temperature around the frame of the window. This is consistent with the exterior view and illustrates the difference in energy efficiency between the quad-pane window and the other windows.

Hallway

The cable pass-through in the ceiling into the dome (Fig. 38) is packed with loose insulation in the cavity. The angle at which the photographs was taken makes it is difficult to see, but the cables bend to go through the hole in the ceiling. Maintaining this as the only hole feeding into the radome, and insulating the void, is recommended to minimize the number of penetrations through the building envelope. Note that, in the foreground, there is a hole in the wall between the hallway and the kitchen.

Office

There are leaky locations that run the length of the northeastern corner in the office and also where there are bolts coming through the envelope attached to a piece of lumber on the outside (Fig. 39). Similar to the bolts through the ceiling in the kitchen, the bolts through the wall in the office are thermal bridges. Not visible on the interior is a warm spot on the wall (the location is noted on the visual image) that was visible in the exterior IR imagery.

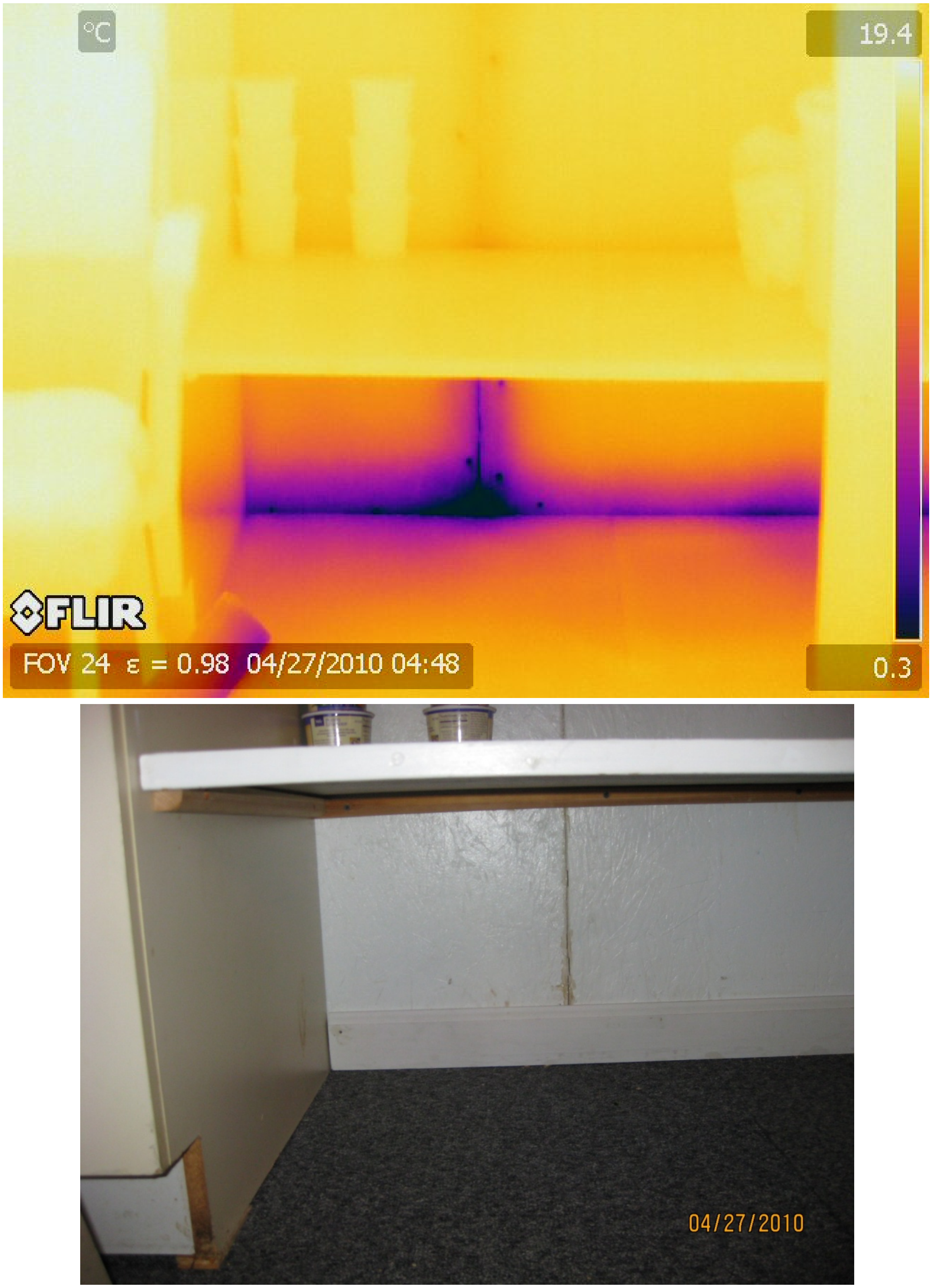


Figure 36. IR and visual images of the cold location under the counter in the main room before it was sealed.

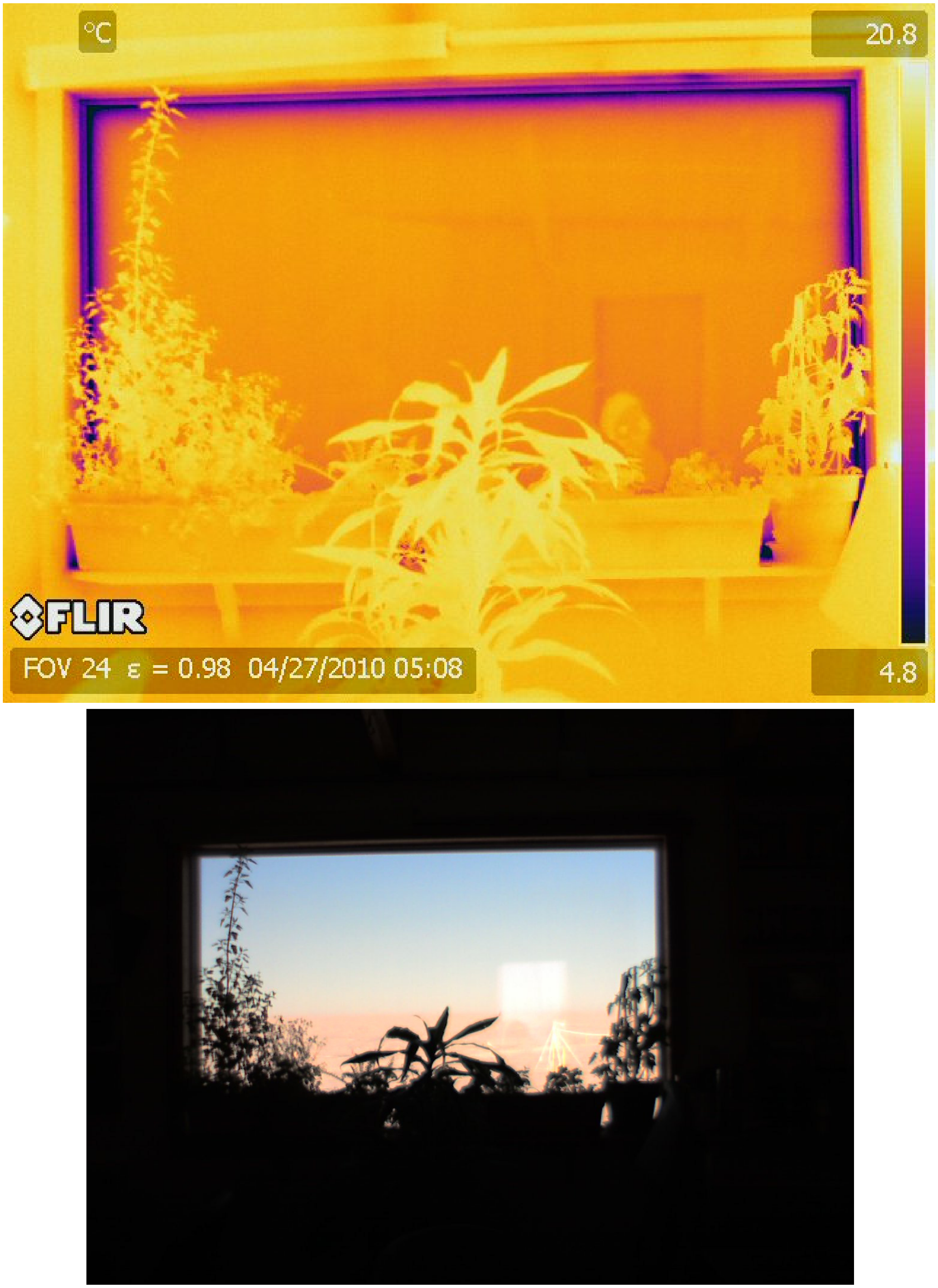
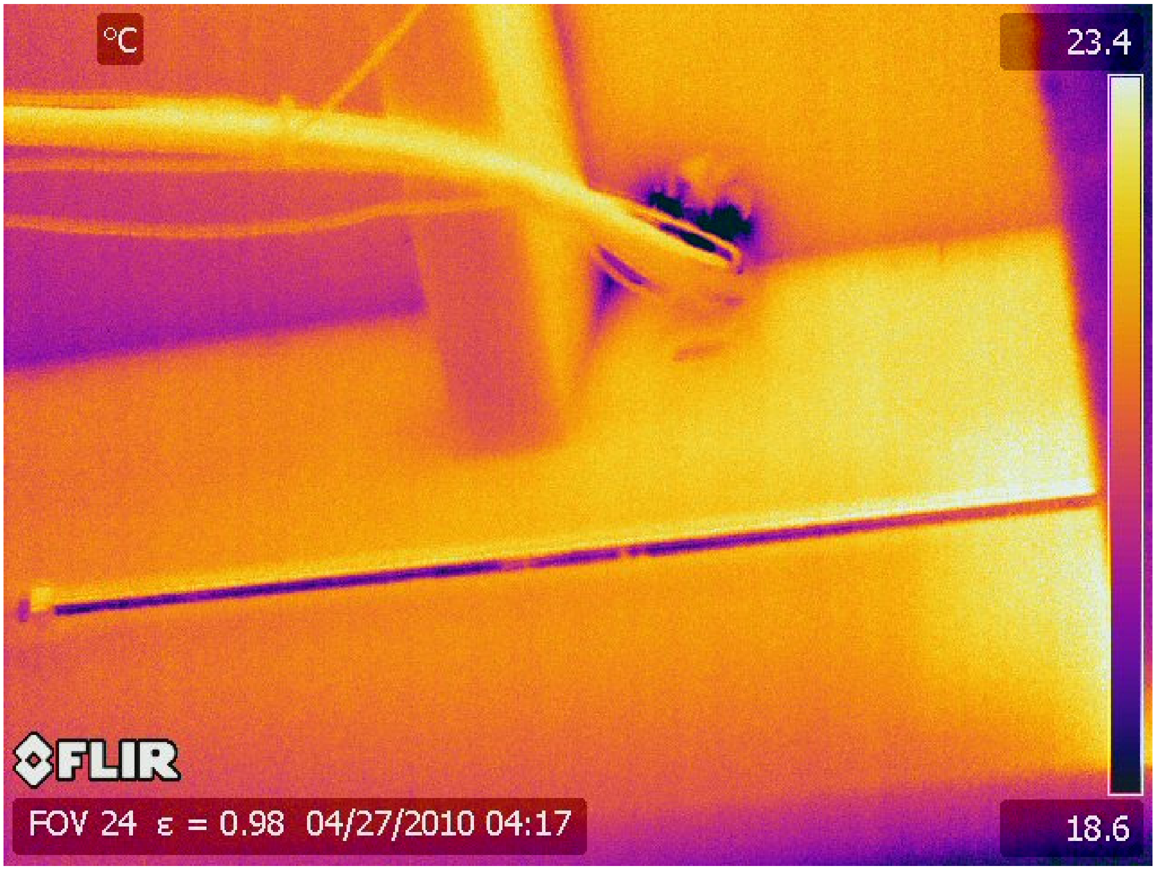


Figure 37. IR and visual images of the quad-pane window in the main room.



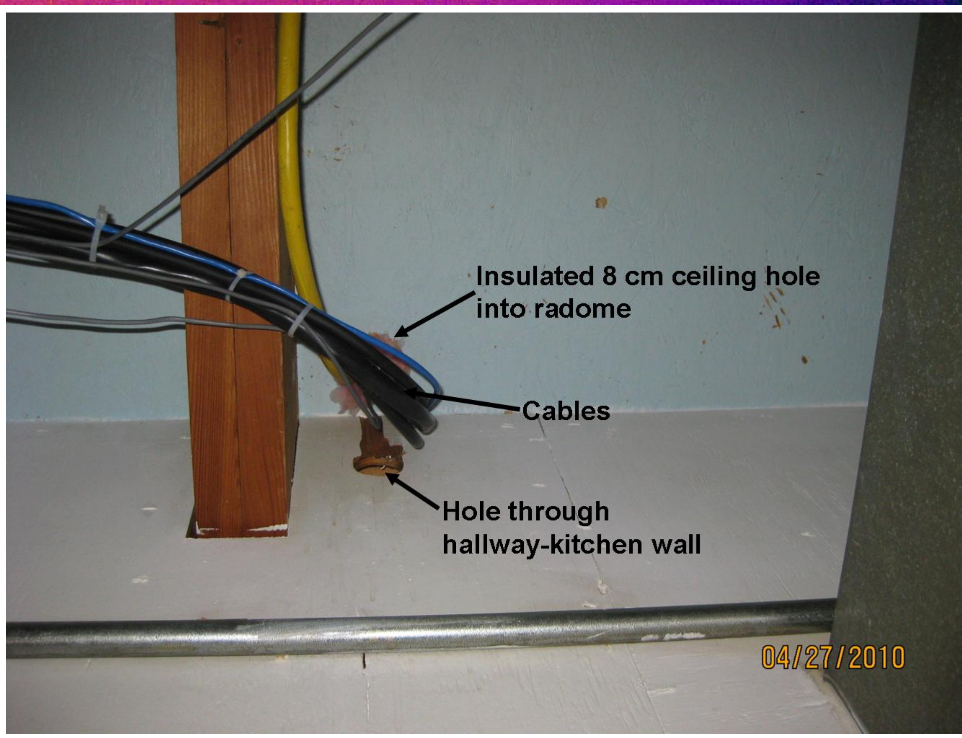
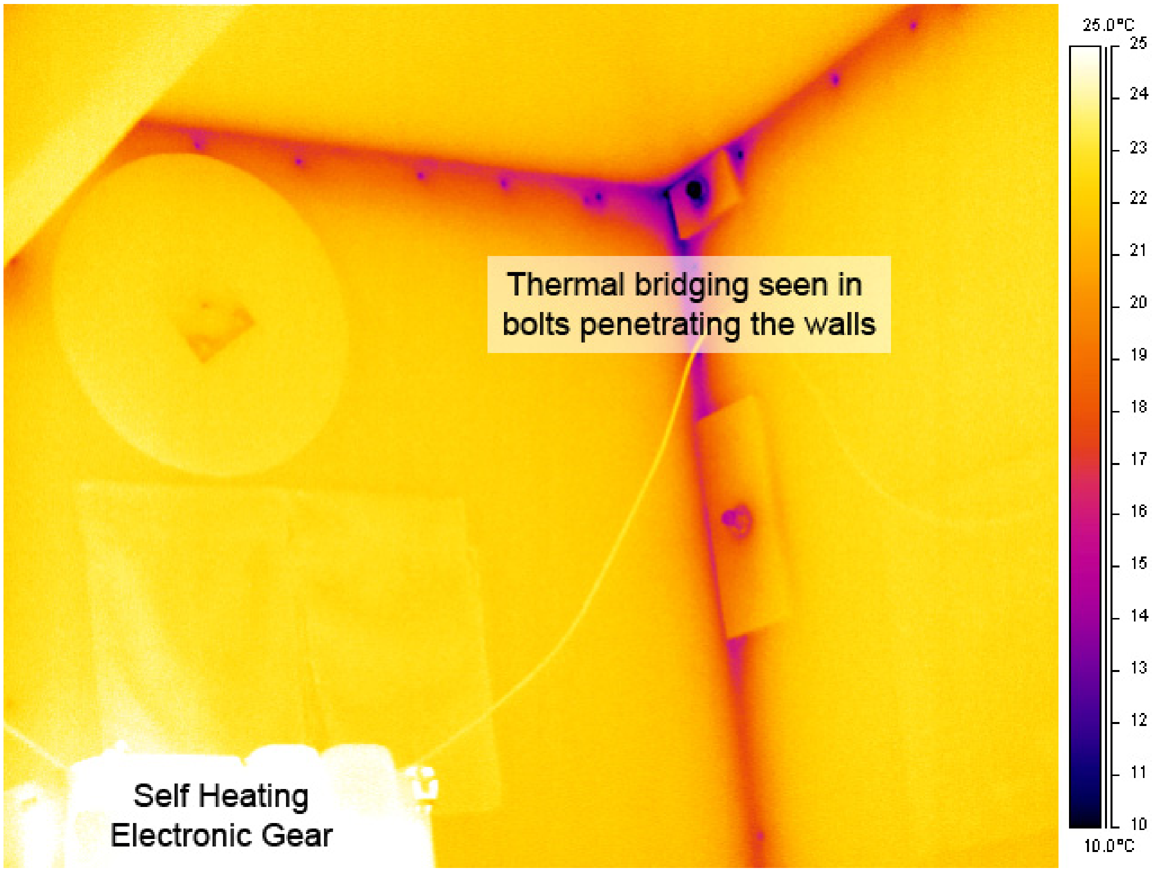


Figure 38. IR and visual images of the ceiling in the hallway where cables pass through into the radome.



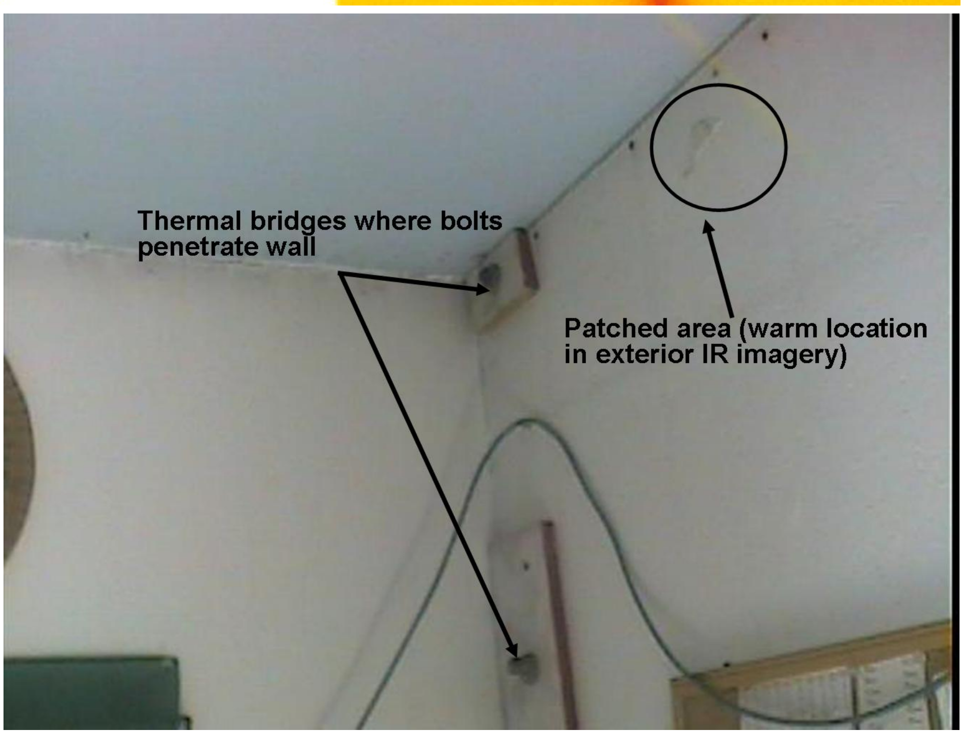
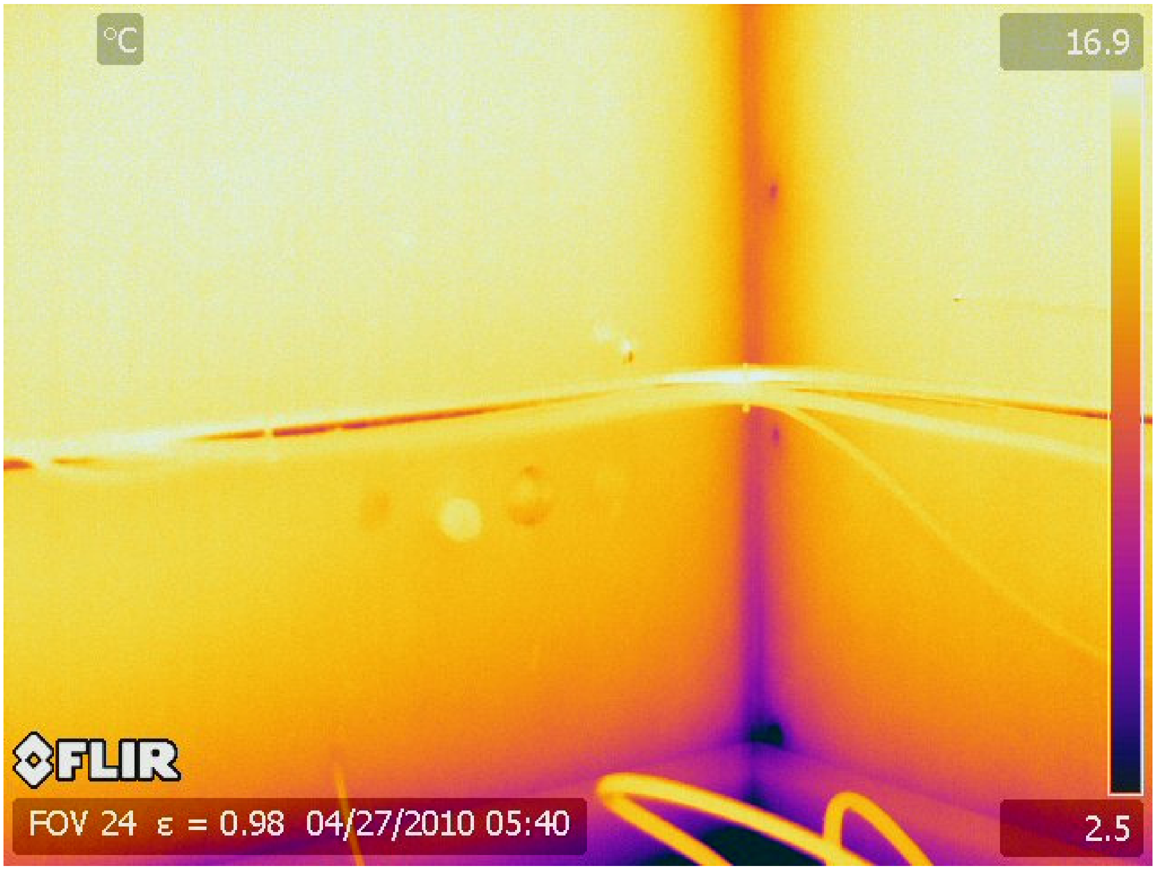


Figure 39. IR and visual images of the northeastern corner in the office.



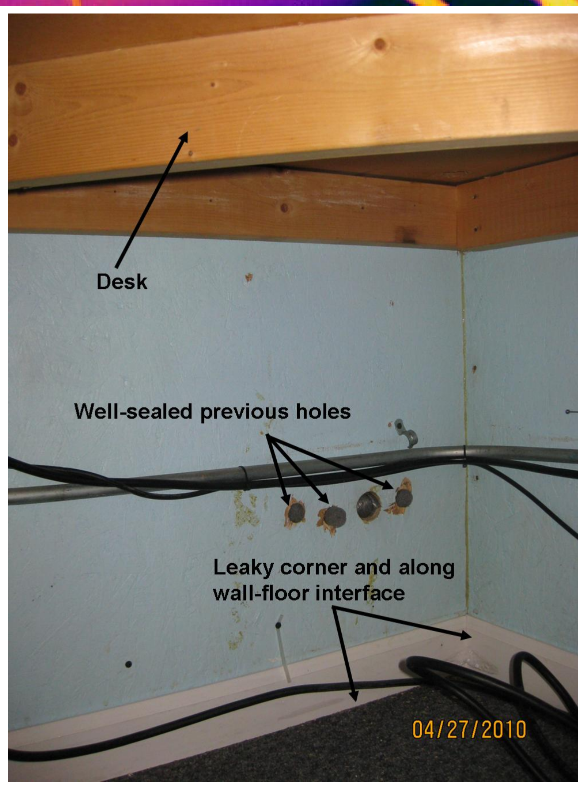


Figure 40. IR and visual images of the north-eastern corner below the desk in the office.

Below the desk (Fig. 40) are leaks at the corner and the wall–floor interface, with similar temperatures as the cold location under the counter in the main room. There are boxes and items stored under the desk that may be insulating this area so that the cold may not be noticeable to people working there. Also under the desk in this same wall were several holes that were well-sealed and did not show up in the IR imagery. It is recommended that previous penetrations to the building envelope that are no longer needed to support instrumentation be removed and completely re-insulated and sealed.

Laundry Room/Bathroom

In the laundry room/bathroom (Fig. 41), the IR image shows the vents for the clothes dryer (top) and the through-wall vent (the dark image below and to the right of the clothes dryer vent). The visual image in Figure 41 only shows a closeup of the lower through-wall vent. The through-wall vent is a direct pathway for cold air to enter into the building, as seen by the dark color of the vent in the IR image, and also in the frost buildup in the visual image. At the time the IR image was taken, the clothes dryer vent was in use and vented the warm, moist air into the room with the use of a diverter. Some warm air is getting vented to the exterior, as ice buildup is present on the outside wall (Fig. 15, exterior **View 2**). A damper, or more durable hardware to fully close the vent when not in use, would be useful to keep cold air out. To move warm, moist air out of the laundry room/bathroom area, a vent that is opened and closed automatically may solve this issue. Similarly, installing durable, exterior hardware to seal the through-wall vent would block cold air infiltration. (It should be noted that the through-wall vent is no longer an issue as it was removed later during the 2010 summer season, after the field visit to conduct the IR survey, and the hole was insulated and sealed [CPS 2010]).

Another possible solution would be to remove and seal up the direct vent hole in the north wall and move this vent to an internal location, such as the wall between the laundry room and scullery, or the wall between the laundry room and hallway. Moving this warm, moist air within the Big House would serve to disperse the humidity where it is needed into the main room. This would also alleviate the ice buildup on the North exterior wall.

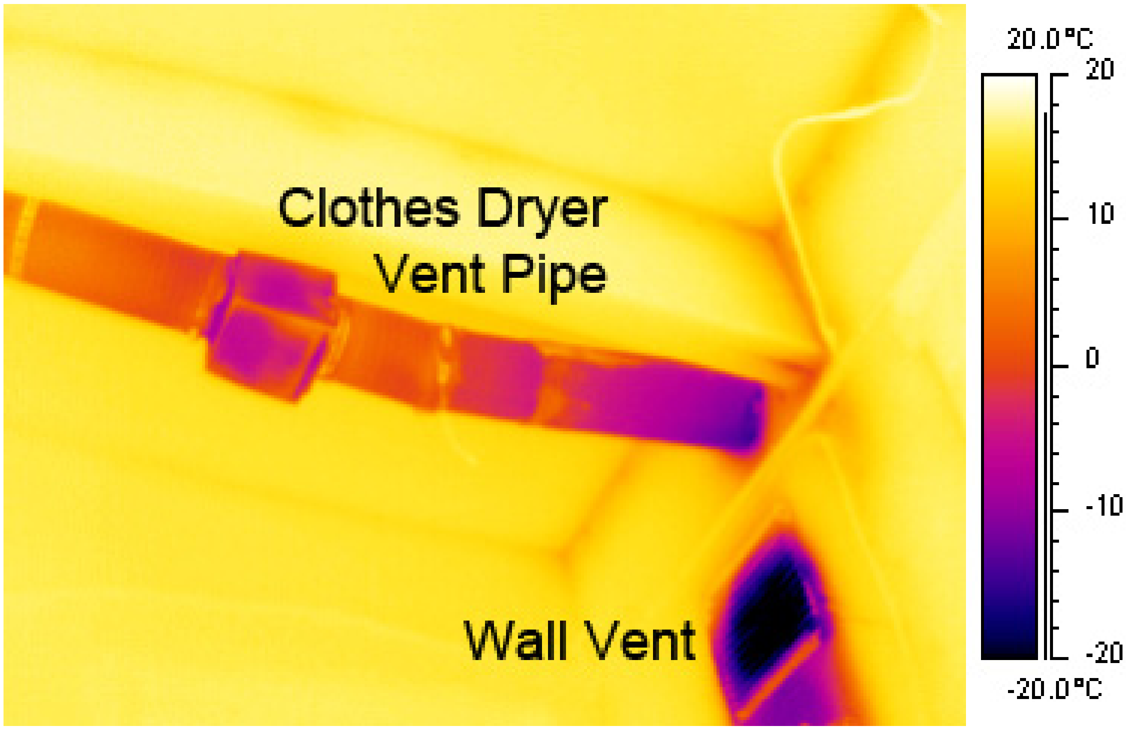


Figure 41. IR image of both the clothes dryer and through-wall vent in the laundry room/bathroom. The visual image is a closeup of the through-wall vent noting frost buildup from cold air infiltration.

Figure 42. IR and visual images of the main entrance door in the east vestibule.

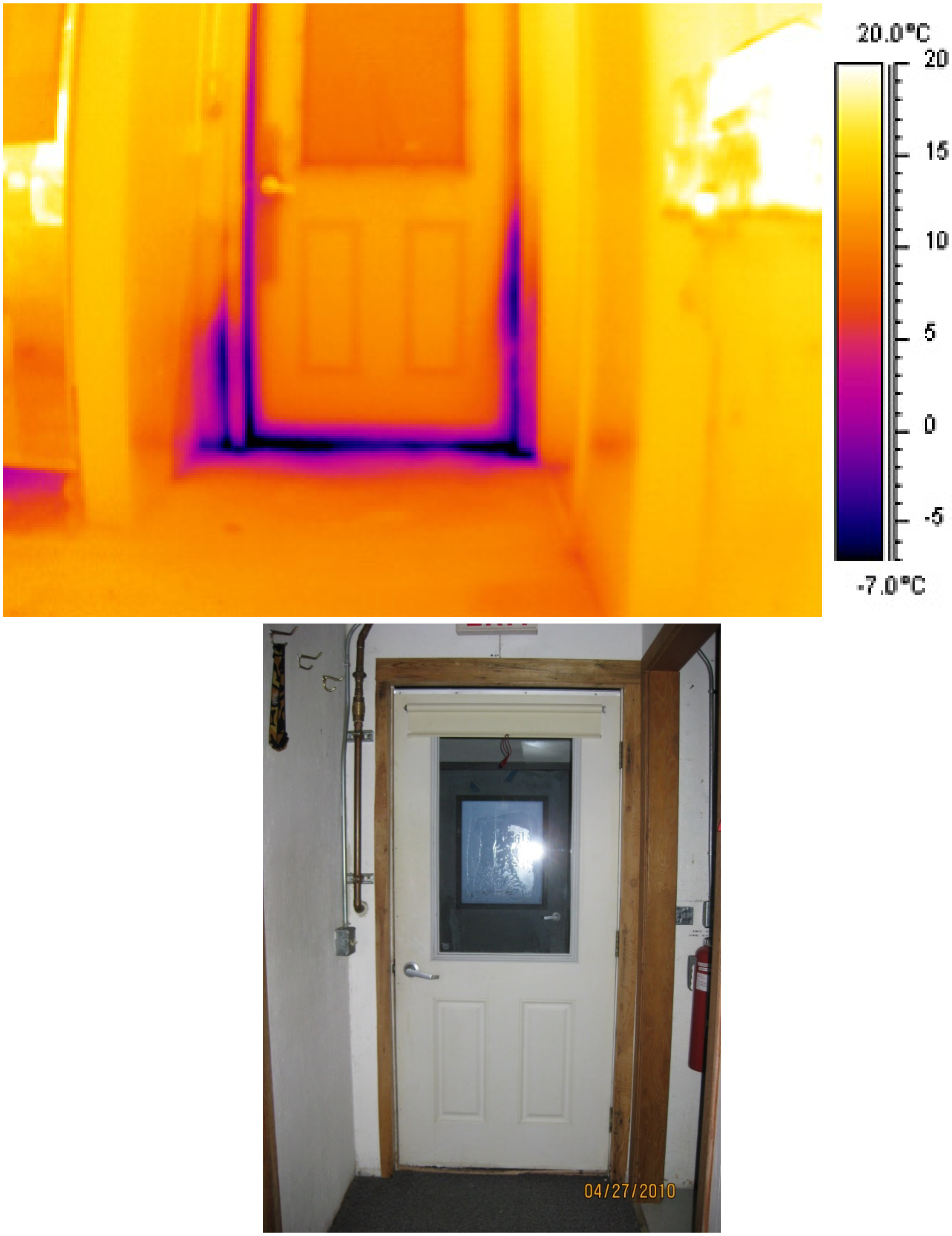


Figure 43. IR and visual images of the main entrance door in the west vestibule.

Vestibule entry doors

Figures 42 and 43 show the IR and visual images of the entry doors into the main room from the east and west vestibules, respectively. The door on the east side appears to have been sealed better, as there is less air leakage along the interface with the floor. The IR

image in Figure 43 for the entry on the western side shows significant air leakage at the threshold under the door and along the sides. The framing in the wall is visible in the IR image, suggesting that additional insulation or sealing may be needed. This entryway receives heavy traffic as it is used to carry heavy boxes and items to the kitchen for food preparation.

Racking

Periodically, the accumulation of snow requires that the entire structure be lifted to maintain clearance above the snow surface. The Big House has been lifted on four occasions for a cumulative height of 15 m. The most recent lift occurred during the 2010 summer when it was lifted approximately 4.5 m.

The lifting procedure requires lengthening, when necessary, the steel columns to provide vertical height. The height of the column is typically sufficient for two lifts, and as a result extensions are added every other lift. Hydraulically operated jacks are placed between the center traveler of the column and the lower jack stand (Fig. 44) (CPS draft).

Figure 44. Position of hydraulically operated jack for lift procedure (CPS draft).

For previous lifts, each column was lifted separately. A new hydraulic pump system was designed and used during the 2010 summer season that allowed the entire structure to be lifted, decreasing the amount of time needed to lift the building. Figure 45 shows the Big House after it was lifted during the summer 2010 season.

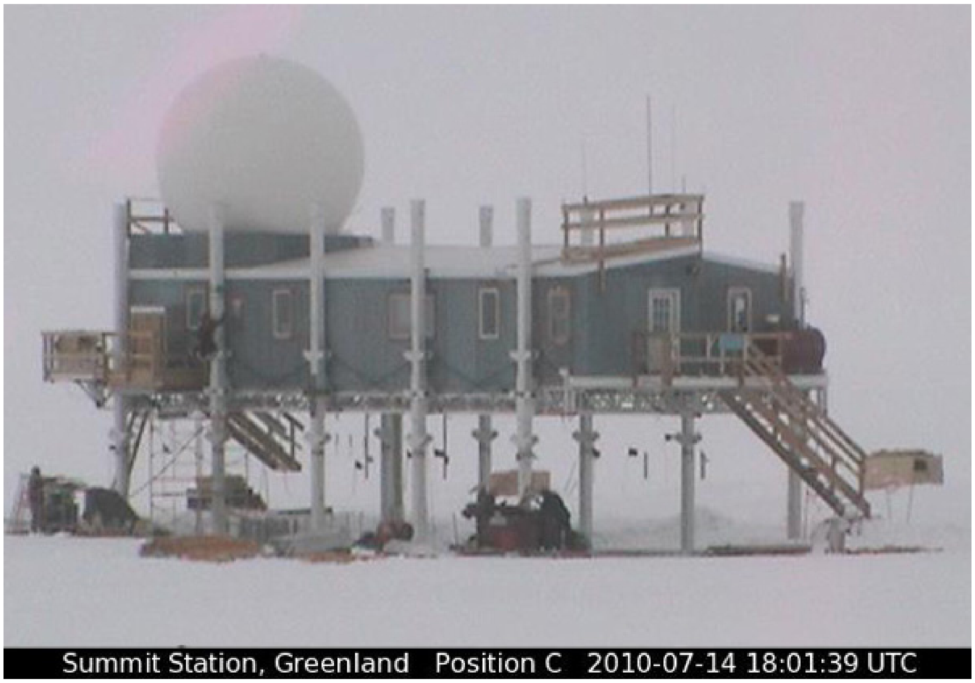


Figure 45. Completed lift of the Big House during the 2010 summer season.

On the occasions when steel to extend the columns is not required, the process of lifting the Big House requires approximately 3 weeks. A 5-person crew conducts the lift, consisting of two carpenters and trades helpers, plus an electrician, to disconnect and re-connect the utilities. The crew plus the cost of the materials required to extend the stairs and utility connections, plus the costs for the lifting system and regular maintenance, give an estimated baseline price of $49,212 (fiscal year 2011 estimate). The steel needed for the extensions is typically purchased 2 years in advance of the lift, coinciding with a year without a lift, and increasing the baseline cost to $87,212 (fiscal year 2011 estimate). It is difficult to estimate the future cost of steel as it is subject to market price fluctuations. However, the median inflation rate of steel between 1982 and 2003 was 3.96% (based on 2010 U.S. Geological Survey data on *Iron and Steel Statistics*). Steel price volatility can be much greater, as has been the case since 2004, with the largest price variation in 2008. Steel prices increased 20% in 2008 and subsequently dropped by 25% in the next year (USGS 2010). A baseline estimated cost for lift

years needing steel extensions was $189,461, based on costs incurred during the 2010 lift. During “non-lift” years, costs are minimized and the estimated baseline cost is $1500.

A total cost of $1.92 million for future lifts of the Big House was estimated for the next 20 years. This estimate assumes that the Big House is lifted every 2 years (based on the period between the 2008 and 2010 lifts), that steel extensions are needed for every other lift, that the same quantity of steel would be required, that the average annual inflation rate of 2.57%—rate averaged from 2000–2010, using data from

http://www.inflationdata.com/inflation/inflation_rate/currentinflation.asp

would apply for labor and materials, and that steel would see an annual inflation rate of 3.96%. Applying a contingency rate of 20% increases the estimated cost to $2.31 million. This also assumes that no significant changes occur to the structural integrity of the Big House over this period.

Overall, the Big House is performing very well, given its age, combined with being lifted four times. Based on the IR survey, there does not appear to be significant racking of the structure. This was observed in the minor separation of the interior wall seams between the SIPs. The improved hydraulic lifting system used during the 2010 summer should reduce the potential for racking as the entire structure is lifted all at once. Provided that insignificant racking of the building from lifting continues, and that no distortion of the foundation occurs, lifting of the Big House may continue for the foreseeable future. It is recommended that periodic IR surveys, perhaps every 5 years, be conducted following a lift to monitor any progression of racking.

5 Conclusions

The Big House at Summit Station, Greenland, is the main facility supporting overall station operations, and providing common areas for dining, washing, and leisure for camp attendees and staff. The Big House has served in this capacity since its construction in 1989. As the National Science Foundation (NSF), and its operations contractor CH2M Hill Polar Field Services (CPS), consider their long-range plan for Summit Station, the current condition of the Big House was assessed for two reasons: 1) to improve the energy efficiency of the building by identifying existing deficiencies that may be addressed; and 2) to identify structural improvements or rehabilitations that may increase the building's service life.

Personnel from the U.S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (ERDC-CRREL) visited Summit Station from 24 to 29 April 2010 to conduct an infrared (IR) survey. Thermography is a useful tool to quickly and easily identify variations in the thermal properties of buildings that result in temperature changes. Deficiencies attributable to inadequate insulation, drafts, or damage from moisture that may not be readily identified with the naked eye are revealed through IR images. In the case of the Big House, disturbances that have resulted from lifting the building were also considered.

Given how well the Big House has performed over the past 20 years, there are many lessons that have been learned about operating and maintaining an elevated structure of this type in harsh conditions. These "lessons" should be documented to help others better understand what has worked successfully and what has not. Additionally, these lessons from the Big House provide an excellent knowledge base from which to draw for the long range plan for Summit Station.

Infrared imagery

In all, roughly 1050 exterior and interior IR images were collected during the field visit. Images are available at the following website:

http://www.crrel.usace.army.mil/sid/SummitGreenland/

To reduce the effect of solar loading, the exterior IR survey was done between the hours of 2130 to 0400 during twilight when the sun set below the horizon, but some light remained in the sky. Air temperatures at the time of the exterior IR survey were about −31°C. Both of the CRREL IR cameras are rated to operate in environments as low as −40°C, and the temperatures encountered at Summit Station did not interfere with the IR survey. The interior temperature of the Big House is maintained at approximately 20°C; therefore, there was no issue with the temperature differential between the exterior and interior temperature conditions to acquire images.

Indoor temperature and relative humidity variations

Indoor temperature and RH measurements were made at 1-minute intervals during the field visit using four dataloggers. The main common area and the kitchen were monitored during the entire visit. In an effort to collect readings from as many locations as possible, roaming dataloggers were initially set for at least 24 hours in the west vestibule and the mechanical room and then repositioned in the east vestibule and laundry/bathroom. Coordination with CPS allowed the data collection to continue through the summer season in the main room and kitchen.

Racking and penetrations

Overall, the Big House is performing very well, given the age of the structure, combined with lifting the building four times for a rough total height of 15 m. Penetrations through the building envelope are the principal sources of energy loss in the structure. An inclusive list was generated by CPS personnel locating and describing existing penetrations (Appendix A). While a number of these were anticipated, including doors and windows, there were also many smaller holes identified ascribable to running cables for sensors and connection points (bolts) that act as supports. Several additional penetrations were identified during the ERDC-CRREL field visit, primarily ones that were not as easily visible. Major penetrations to the various building surfaces (walls, roof, and base), along with recommendations for mitigation, are noted here.

Racking

Significant impacts from the periodic lifting of the building were not observed in the IR imagery. Particularly, the separation between seams in abutting structural insulated panels (SIP) in the walls was minor.

Vents

At the time of the IR survey, an air vent centrally located on the north wall in the laundry room was a direct pathway for cold air to infiltrate into the building. This through-the-wall vent is no longer an issue as it was removed later during the 2010 summer season. The hole was insulated and sealed (CPS 2010). Another possible solution would be to remove and seal up the direct vent hole in the north wall and move this vent to an internal location, such as the wall between the laundry room and scullery, or the wall between the laundry room and hallway. Moving this warm, moist air within the Big House would serve to disperse the humidity where it is needed into the main room. This would also alleviate the ice buildup on the north exterior wall.

The vent for the clothes dryer in the laundry room was another penetration where the mixing of cold air with the expelled heat from the dryer created ice buildup on the outside of the building.

IR imagery taken from the outside of the Big House shows the effect of using the stove vents to draw warm air to the outside. Conversely, when the vents are not in use, cold air infiltrates the building through the vents.

It is likely that the vent with the greatest influence is the direct fresh air vent (600 × 600 mm in the west vestibule feeding air into the kitchen above the refrigerators). This vent is manually controlled and supplies a great amount of fresh air to the building, as well as, make-up air for any combustion devices (such as the stove and furnace). A heat exchanger may be useful to regulate this vent.

Doors

The IR imagery shows heat loss around both the east and west vestibule exterior doors, likely from wear on the door seal, as well as

through the window. Both of these doors are insulated residential doors with a viewing window in the upper half of the door.

Windows

The exterior IR imagery of the building taken on the south side in the vicinity of the large, fixed window clearly showed little temperature variation at the quad-pane window location.

The exterior IR imagery of the double-paned windows showed more heat loss than the imagery of the quad-pane window.

Roof

Modest heat loss was observed in the IR imagery through the roof members over the main building and is not considered a big contributor.

The access hatch to the roof penetrating the ceiling in the unheated east vestibule is a source for heat loss and creates a buildup of frost along the interior of the opening. Heat sources are the shared wall with the main room, and the sunlight that comes through the southern window.

Relocating the roof access hatch into an unheated vestibule was a sensible modification. The large size (760 × 914 mm) of the penetration through the ceiling and roof would be difficult to seal to minimize heat loss. The previous opening, where the old roof access hatch was located, is well sealed. No cold air infiltration was observed from inside the Big House at the old access hatch location.

The radome on the roof was not observed to be a significant contributor to heat loss. However, there is some heat loss from the inside of the Big House where the cables run through the ceiling up into the radome.

More heat loss was observed in both the IR imagery from inside and outside the Big House at the roof line where the rafter beams connect to the wall structural insulated panel (SIP) at the joint locations, compared to the wall system.

Similarly, more heat loss was observed along the south side fascia, particularly toward the eastern end of the building, where instru-

ments had previously been installed and in locations where repairs had been made to the metal flashing.

Walls

IR imagery collected from the exterior of the building indicated that the joints between the SIP show limited air leakage, suggesting that the joints continue to perform well and do not show signs of stress resulting from lifting the building.

On the main floor, where the wall is joined to the deck, there are several locations where cold areas were identified. Locations that appeared to have more heat loss included a cold spot under the counters in the main room (which was immediately caulked), an area in the northeastern corner of the office (which may not be noticeable because of storage under the desk), and a location in the bathroom along the baseboard where frost had developed.

Very high heat loss was observed at the southwestern corner of the structure where the east vestibule connects to the main building. This location was identified and noted for repair when the penetration survey was conducted by CPS.

Base

The IR imagery of the exterior base of the structure did not show significant heat loss through the floor. Other than open active vents, the blocked-off vent in the floor of the mechanical room was the only bright spot in the IR imagery.

Recommendations for mitigation

The following recommendations are provided for the Big House to address the areas indicating heat loss from the IR survey:

- Repair the vent in the laundry room to operate effectively, possibly through the use of an automated system, in removing warm moist air from the clothes dryer from inside, yet when not in operation, is securely closed with cold climate dampers.
- Repair the direct vent in the laundry room.
- Replace the remaining double-paned windows with triple-pane windows, which will improve the energy efficiency. This task has been identified and planned by CPS to take place in the near fu-

ture. Insulating between the rough opening and window frame, as well as sealing, is very important.

- Continue to periodically locate and seal up areas where cold air infiltrates the building.
- Explore appropriate dampers to prevent cold air leakage into the building via the stove vents.
- Reduce heat loss around the exterior doors in both the east and west vestibules by replacing the seals.
- Remove the windows in the east vestibule if they are not necessary to reduce moisture buildup. Another method to reduce the amount of moisture buildup in arctic entryways is to maintain a constant cool environment (between 2 to 5°C), to mitigate the large temperature swings in an unheated vestibule.
- Reduce heat loss through building envelope transitions. While windows and doors are essential to the function of a building, they create discontinuities in the building envelope and reduce the thermal resistance of the wall system. Doors and windows can be improved with good frames and installation procedures.
- Create an effective arctic entry. The entry way doors in the Big House are scheduled to be replaced with freezer doors. A standard and effective arctic entry design locates entryway doors with the tightest seal closest to the warm side of the building. This design recommends that exterior entryway doors to vestibules allow more air leakage. The tight seal created between the main building and the vestibule, by installing the freezer-type doors here, would reduce heat loss and keep moisture out of the vestibule. Conversely, installing freezer-type doors at the exterior entryway, further away from the warm side of the building, would trap moisture. With the type of exterior vestibule (arctic entry) doors currently installed, moisture can escape as these doors are not as airtight as the freezer doors.
- Regularly replace the seals on the Green House freezer-type doors. These were installed with some damage to the seals. Annual inspection would maintain the working condition of the doors.
- Repair the two gaps on the southwestern side of the building at the interface where the west vestibule connects to the main building and the gap at the southwestern corner.
- Test the air tightness of the Big House using a blower door test.
- Use an IR camera following a lift of the Big House to detect any areas of the building where the thermal envelope may be compromised.

- Develop a formal procedure to seal up penetrations in the building where openings for cables exist and especially where cables have been removed.
- Run cables through a common access conduit that penetrates through the building envelope and connects to outside sensors. A common access conduit may be sealed to keep cold air out.

References

ACR Systems, Inc. (2010). *Product specifications for SmartReader Plus 2*. Surrey, BC, Canada: www.acrsystems.com.

AIA Alaska (2004). *Northern building design*. Anchorage, AK: American Institute of Architects.

Anderson, D. (2010). Personal communication. 29 July, Winter Panel, Brattleboro, VT.

Armstrong, R. (2010) *Energy analysis various buildings, Summit Station, Greenland*. Anchorage, AK.

ASHRAE (2009). *Fundaments handbook*. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.

Baring-Gould, I. E. and J. O. Roberts (draft) *Power system design report, Summit Station—Model 5*. Golden, CO: National Renewable Energy Laboratory.

CPS and NSF (2009). Personal communication, 16 November.

CPS (2010) Personal communication with CH2M Hill Polar Field Services, 4 November.

CPS (2009a) Personal communication with CH2M Hill Polar Field Services, 17 November.

CPS (2009b) *Model 5 requirements for modernization of Summit Station*. Littleton, CO: CH2M Hill Polar Field Services.

CPS (2010) *Big House floor plan*. Littleton, CO: CH2M Hill Polar Field Services..

CPS (draft) *BH lift procedure*. Littleton, CO: CH2M Hill Polar Field Services..

Curtis, K. C., and W. Tobiasson (1991). Processed-snow foundation design at the Summit of the Greenland Ice Cap. *Cold Regions Sixth International Specialty Conference, TCCP/ASCE*. 26–28 February West Lebanon, NH.

FLIR® (2009) *User's manual, FLIR bXX series and FLIR iXX series*. FLIR systems, USA.

Freitag, D., and T. McFadden (1997). *Introduction to cold regions engineering*. New York, NY: American Society of Civil Engineers.

Osgood, S., and D. Bornstein (1989) DYE-2 and DYE-3—A 30 Year Engineering History. *Proceedings of the Fifth International Cold Regions Engineering Specialty Conference, 6–8 February 1989, St. Paul, Minnesota*. New York, NY: American Society of Civil Engineers.

Tobiasson, W. (unpublished) *Preliminary design of the first "permanent" building at the GISP-2 site in Greenland*. Hanover, NH: U.S. Army Cold Regions Research and Engineering Laboratory.

U.S. Geological Survey (2010) Iron and Steel Statistics, *in* Kelly, T.D., and G.R. Matos comps., Historical statistics for mineral and material commodities in the United States: U.S. Geological Survey Data Series 140, accessed 24 February 2011, at http://pubs.usgs.gov/ds/2005/140.

Appendix A: Penetration survey

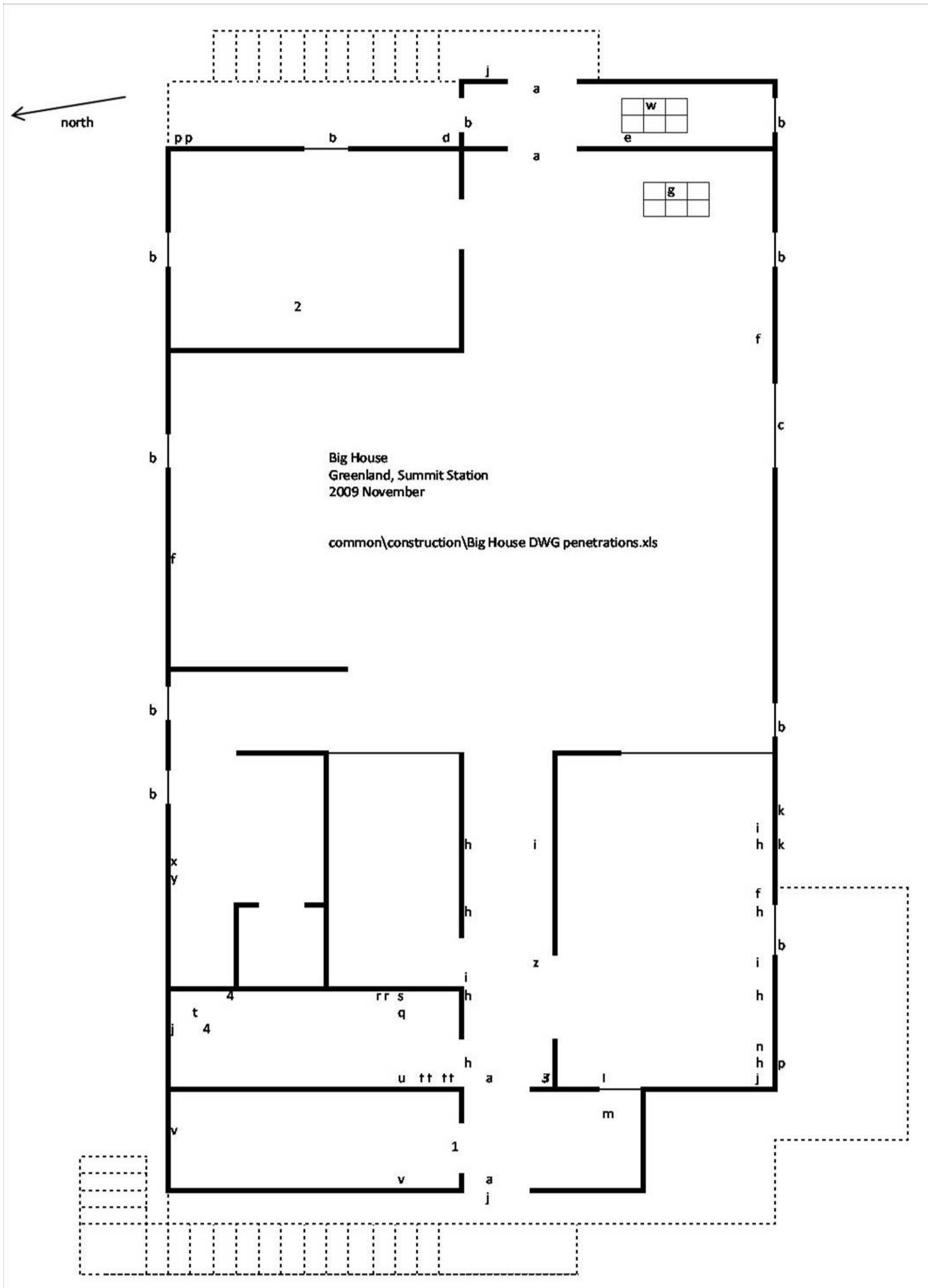


Figure A-1. Penetration survey conducted by CPS (Mark Melcon "Commander," November 2009).

Table A-1. Notes of penetration survey (CPS, November 2009).

Big House Penetrations Common\construction\Big House Penetrations.txt

2009 November
17th Tuesday

Walls are 8 in. thick: 5 in. SIP (1/2 in. OSB + 4 in. yellow open cell[a] + 0.5 in. OSB + metal cladding) + 1.5 in. closed(?) cell foam[b] + 0.5 in. T-1-11.

Roof is 9 in. thick: 5 in. SIP + ~3.5 in. foam + 1/2 in. unknown panel, + steel roofing.

Note that architect fts drawings from 1989 specified 4.5 in. SIPs.

Original building was 26 ft-10 in. x 56 ft-0 in. outside measurement, oriented E-W. Ceiling is 7 ft-10 in. along long walls and 9 ft-7.5 in. at ridge.

Added on the east end, south side, is a 4 ftx 13 ft vestibule with 7 in. walls. This is probably 2x4 construction with 0.5 in. ply on both side, with 1.5 in. foam[c] insulation and 0.5 in. T-1-11 added later.

Added on the west end, north side is a 6 ft-6 in. x 21 ft-6 in. walk-in cooler and pantry.

On the east and west ends are FiberGrate(R) decking and stairs, currently ~12 in. down to the snow surface.

A	36 in. x 80 in. door with 21 in. x 35 in. (exposed glass) double-pane window, @4
B	23 in. x 43 in. (exposed glass) double-pane window, operable, @10
C	67 in. x 40 in. (exposed glass) double[d]-pane window,
D	1.5 in.d antenna cable hose near ceiling, not sealed
E	8 in.d hole low wall, plugged insulated and sealed
F	1 in.d conduit hole in floor, @6
G	30 in. x 36 in. ceiling hatch removed, insulated and sealed (?)
H	3/8 in. bolt thru ceiling, with 2x6 to distribute load, @8
I	1/2 in. bolt thru ceiling, with 2x6 to distribute load, @4
J	1 in.d hole in wall, filled @4
K	3 in. x 14 in. discharge stove vents, @2
L	24 in. x 24 in. hand-operated louvered hole, high on wall behind freezer. It connects to M.
M	24 in. x 24 in. vertical shaft (not insulated) to hole in floor
N	3 in.d hole high on wall, foamed
P	1/2 in. bolt thru wall, high, @3
Q	8 in. x 10 in. floor grill, furnace air supply

[a] High density isocyanurate foam insulation (29 July 2010 personal communication with Dough Anderson, Winter Panel, Brattleboro, VT)

[b] Open cell expanded polystyrene insulation

[c] EPS is not thought to be under the T-111 siding (communication 04 Nov 2010)

[d] Quad-pane window

Big House Penetrations Common\construction\Big House Penetrations.txt

R	1 in.d steel pipe in floor, @2
S	1 in. x 3 in. floor slot, not insulated
T	4.5 in.d ABS sewer pipe in floor, within poorly insulated 15 in. x 24 in. hole. 4 in. ABS vent thru roof.
U	1.75 in. armored cable in 2 in. floor hole
V	8 in.d vent with fan thru middle of wall, with outer duct to floor level
W	30 in. x 36 in. ceiling hatch, operable
X	4 in.d dryer vent high on wall
Y	8 in.d vent, summer use, sealed for winter, high on wall
Z	3 in. ceiling hole, takes cables to dome
1	36 in. x 80 in. insulated door
2	unknown floor penetration, not used, covered by carpet, boxed in below floor
3	1 in.d copper water pipe in middle wall
4	1/2 in. bolt thru floor, @2
5	1 in.d holes for coax, high on wall
6	in.6 1 in.d hole in wall above floor @ 3; and a 1.5 in.d hole, north wall east end, all plugged with foam rod and not showing on IR.

Not noted on drawing, on top of the long walls there are 3 in. x 9 in. beam pockets 4 ft on center. Presumably these extend 4.5 in. to the original outer layer of OSB.

Appendix B: Station population

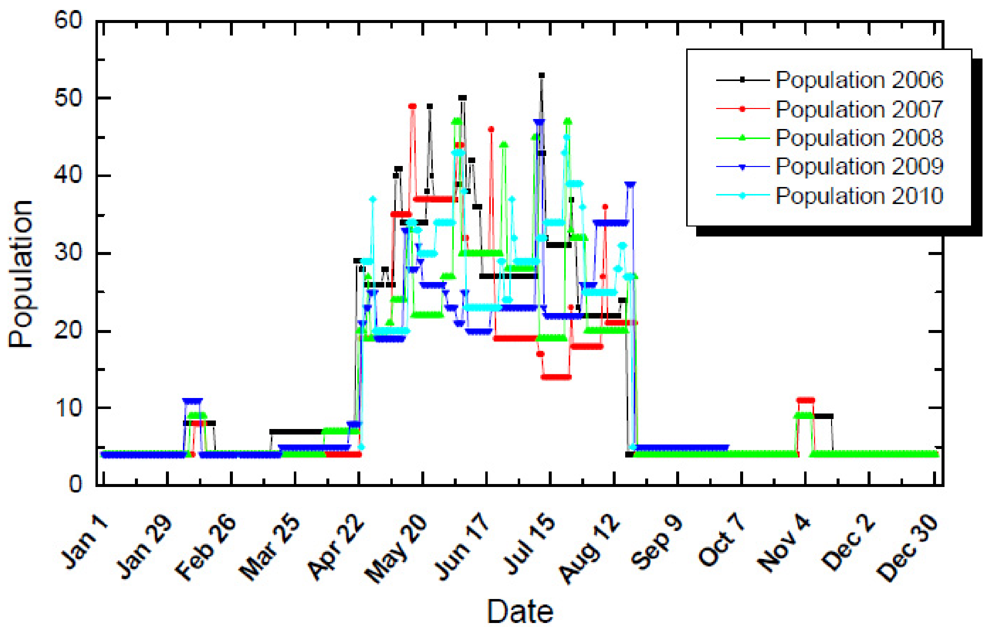


Figure B-1. Summit Station population from 1 January 2006 to 20 August 2010 (Source: CPS). (This information tracks Summit's overnight population) the 2010 summer season closed at Summit on 20 August 2010.

Table B-1. Cumulative monthly overnight population for Summit Station from 2006 to 2010.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2006	124	164	175	410	1068	989	936	436	120	124	195	124
2007	124	132	124	240	1047	873	522	484	120	124	169	124
2008	124	151	124	311	728	963	853	488	120	129	150	124
2009	124	161	137	307	755	658	778	726	150	A	A	A
2010	A	A	A	198*	842	851	1037	504**	A	A	A	—

A Data not available

* Data from 23–30 April 2010

** Data from 1–20 August 2010

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* April 2011	**2. REPORT TYPE** Final	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Engineering Assessment of Big House at Summit Station, Greenland		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Lynette A. Barna, Keran J. Claffey, James S. Buska, and Jennifer L. Mercer		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Cold Regions Research and Engineering Laboratory U.S. Army Engineer Research and Development Center 72 Lyme Road Hanover,NH 03755-1290		**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/CRREL TR-11-10
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Science Foundation, Office of Polar Programs Research Support and Logistics Division Arlington, Virginia		**10. SPONSOR/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

An infrared (IR) assessment was conducted of the main administration building located at Summit Station, Greenland. The building, known as the "Big House," was constructed in 1989 on a permanent snowfield at the apex of the Greenland Ice Sheet. Summit Station typically receives 65 cm of annual snowfall. Accumulating snow combined with blowing and drifting can completely bury a structure in several years. For this reason, the Big House is elevated above the snow surface on steel support columns and it is periodically lifted to maintain clearance above the snow surface. The Big House has been lifted four times for a combined total height of 15 m. The lifting process can damage buildings by causing racking. This IR survey was conducted to identify existing deficiencies in the building that may diminish the energy efficiency or compromise the structural performance, reducing the building's service life. This evaluation found that, in the extreme climate where the Big House is located, the structure is performing quite well after 20 years of service. The most significant issue is heat loss in localized areas through the building envelope. No major structural issues were observed.

15. SUBJECT TERMS

Engineering for Polar Operations, Logistics, and Research
Greenland Ice Sheet
Infrared (IR) assessment
Structural issues
Summit Station, Greenland

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
U	U	U	U	101	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18